Transmission in multi-channel communication system using selective channel power control

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Inventor(s): LING FUNYUN; KETCHUM JOHN W; WALTON JAY ROD; WALLACE MARK S; HOWARD STEVEN J +
Applicant(s): QUALCOMM INC +
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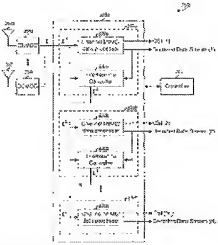
Techniques to process data for transmission over a set of transmission channels selected from among all available transmission channels. In an aspect, the data processing includes coding data based on a common coding and modulation scheme to provide modulation symbols and pre-weighting the modulation symbols for each selected channel based on the channel's characteristics. The pre-weighting may be achieved by "inverting" the selected channels so that the received SNRs are approximately similar for all selected channels. With selective channel inversion, only channels having SNRs at or above a particular threshold are selected, "bad" channels are not used, and the total available transmit power is distributed across only "good" channels.; Inproved performance is achieved due to the combined benefits of using only the Ns best channels and matching the received SNR of each selected channel to the SNR required by the selected coding and modulation scheme.



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(71) Applicant(s)
QUALCOMM INCORPORATED

(72) Inventor(s)
Ling, Funyun; Ketchum, John W.; Walton, Jay Rod; Wallace, Mark S.; Howard, Steven J.

CN1086061A Digital control channel

Assignee/Applicant
Standardized: **ERICSSON GE MOBILE COMMUNICAT**

Inventor
RAITH ALEX K

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Abstract

The present invention provides a method for transmitting information on a digital control channel (DCC 1) between a base station (B2-B9) and a mobile station (M1-M9) in a cellular system. The method includes the steps of grouping the information into a plurality of information elements (E1, E2, E3, ...), providing at least one change flag (F1, F2, F3, ...) to indicate whether the value of at least one of the information elements (E1, E2, E3, ...) has changed and transmitting the change flag (F1, F2, F3, ...) and the information element (E1, E2, E3, ..) over the digital control channel (DCC 1).

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[71]申请人 埃利克逊GE汽车交通股份有限公司

地址 美国北卡罗来纳州

[72]发明人 亚历克斯K·赖特

[74]专利代理机构 上海专利事务所

代理人 颜承根

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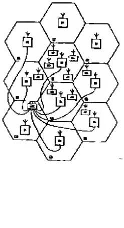
[54]发明名称 数字控制信道

[57]摘要

本发明提供一种在诸如蜂窝区通信系统中基地站与移动台之间的数字控制信道之类的通信信道上传送信息的方法。此方法包括以下步骤，将信息组成多个信息单元；提供至少一个更改标志以指示至少一个信息单元的值已更改；在该通信信道上传送更改标志以及信息单元。



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权 利 要 求 书

1. 一种在通信信道上发送信息的方法，其特征在于包括下列步骤：

将信息组成为多个信息单元；

提供至少一个更改标志，以指示至少一个所述信息单元的值是否已更改；

在所述通信信道上传送所述至少一个更改标志和所述至少一个信号单元。

2. 如权利要求1所述的方法，其特征在于所述通信信道是基地站和至少一个移动台之间的数字控制信道。

3. 如权利要求2所述的方法，其特征在于所述至少一个移动台读出所述至少一个更改标态，以判断所述至少一个信息单元是否已更改。

4. 如权利要求3所述的方法，其特征在于只有所述至少一个更改标志表明其值已更改，所述至少一个移动站才读出所述至少一个信息单元。

5. 如权利要求4所述的方法，其特征在于所述至少一个更改标志包括至少一2进制位，所述至少一个信息单元包括一开销消息。

6. 一种在收信机和发信机上收、发随时间变化且按规则间隔传送的信息的方法，其特征在于包括下列步骤：

与所述信息的每次传送一起，所述发信机发射一个所述信息是否已更改的指示；

只有表明为已更改，所述收信机才读出所述信息。

7. 如权利要求6所述的方法，其特征在于所述发信机包括基地站，所述收信机包括移动台，所述信息包括开销信息。

8. 如权利要求 6 所述的方法，其特征在于所述指示可以设定为至少第一、第二以及第三数值当中的任意一个；所述第一数值表示所述信息未更改，并且不应该读出；所述第二数值表示所述信息已更改，并且应该读出；所述第三数值在所述第二数值传送后传送预定次数，以表示所述信息只有从发送所述第二数值起未被读出过时，才应该读出所述信息。

9. 一种在一信道上进行信息通信的方法，其特征在于包括下列步骤：

将所述信道分成多个子信道；

在至少一条所述子信道中传送所述信息的至少一个部分；

在至少一条所述子信道中传送至少一个更改标志，以指示所述至少一个信息部分何时更改；

接收所述至少一个信息部分和所述至少一个更改标志；

响应所述至少一个更改标志的指示，读出所述至少一个信息部分。

10. 如权利要求 9 所述的方法，其特征在于所述子信道包括：

一快速播发控制信道（FBCCH）；

一慢速播发控制信道（SBCCH）；

一延伸播发控制信道（EBCCH）。

11. 如权利要求 10 所述的方法，其特征在于，

第一信息部分在所述 SBCCH 中传送；

第二信息部分在所述 EBCCH 中传送；

第一以及第二更改标志在所述 FBCCH 中传送，以指示所述第一以及第二信息部分分别何时更改。

12. 如权利要求 10 所述的方法，其特征在于，

第一信息部分在所述 SBCCH 中传送；

第二信息部分在所述 EBCCH 中传送；

第一更改标志在所述 FBCCH 中传送，以指示所述第一信息部分何时更改；

第二更改标志在所述 SBCCH 中传送以指示所述第二信息部分何时更改。

13. 如权利要求 10 所述的方法，其特征在于所述信息在所述信道上以超帧序列的形式通信，每个超帧包括多个时隙，其中，

所述 FBCCH 占据每个所述超帧中的一个时隙；

所述 SBCCH 占据每个所述超帧中的第一规定数量的时隙；

所述 EBCCH 占据每个所述超帧中的第二规定数量的时隙。

14. 如权利要求 13 所述的方法，其特征在于所述至少一个信息部分包括至少一个数据消息，而且长的数据消息在多个连续超帧上的 EBCCH 中传送。

15. 如权利要求 13 所述的方法，其特征在于所述子信道还包括占据每个超帧中一个时隙的播叫信道(PCH)。

16. 如权利要求 15 所述的方法，其特征在于，

第一信息部分在所述 SBCCH 中传送；

第二信息部分在所述 EBCCH 中传送；

第一以及第二更改标志在所述 PCH 中传送，以指示所述第一以及第二信息部分分别何时更改。

17. 如权利要求 15 所述的方法，其特征在于，

第一信息部分在所述 SBCCH 中传送；

第二信息部分在所述 EBCCH 中传送；

第一更改标志在所述 PCH 中传送，以指示所述第一信息部分何时更改；

第二更改标志在所述 SBCCH 中传送，以指示所述第二信息部分何时更改。

18. 如权利要求 15 所述的方法，其特征在于，

第一信息部分在所述 SBCCH 中传送；

第二信息部分在所述 EBCCH 中传送；

第一以及第二更改标志在所述 FBCCH 以及所述 PCH 的每一个当中传送，以指示所述第一以及第二信息部分分别何时更改。

说　明　书

数字控制信道

本发明涉及无线通信系统，更具体地说，涉及一种蜂窝区无线通信系统中在数字控制信道上进行消息联络的方法和装置。

在一典型的蜂窝区无线通信系统中，将一地理区域（例如在大城市区）分作若干个蜂窝区，每个蜂窝区又分别由一无线电波覆盖范围有限的基地站提供服务。基地站与一移动通信业务交换中心（MSC）相连，该中心再接到陆上通信线的公用交换电话网（PSTN）。蜂窝区无线通信系统中的每个用户（移动用户）都有一可搬式、袖珍式、手持式或车载式的设备（移动台），该设备与附近的基地站和 MSC 进行话音通信和/或数据通信。MSC 有助于各类通信，例如在移动台与系统中的其他移动台之间或与 PSTN 中陆上通信线电话机之间交换呼叫和控制信令。图 1 示出根据高级移动电话业务（AMPS）标准所建立的传统的蜂窝区无线通信系统的结构。

在图 1 中会发现一任意地理区域可分成 C1—C10 这样的多个相应邻接无线电波覆盖区（或称为蜂窝区）。图 1 为了说明，所示系统仅包括 10 个蜂窝区，但实际上蜂窝区的数量可以大得多。与 C1—C10 各蜂窝区相关联，并位于各区中的是一标注为与多个基地站 B1—B10 中之一相对应的基地站。各基地站 B1—B10 分别包括多个信道单元，本技术领域众所周知，各个信道单元包括一发信机、一收信机和一控制器。图 1 中，基地站 B1—B10 分别位于蜂窝区 C1—C10 的中心，具有在所有方向上相同发射的全向天线。在这种情况下，每个基地站 B1—B10 的所有信道单元都与一天线相连。但在蜂窝区无线通信系统的其他结构中，基地站可以位于蜂窝区边缘

附近，即不在蜂窝区 C1—C10 的中心，因而可用无线电信号定向辐射蜂窝区 C1—C10。例如，基地站可以配备 3 副定向天线，每一副如图 2 所示覆盖一个 120°扇形区。在这种情况下，某些信道单元就与覆盖某一扇形区的某副天线相连，其他信道单元就与覆盖另一扇形区的另一天线相连，其余信道单元则与覆盖所余扇形区的所余一天线相连。因而，在图 2 中基地站向 3 个扇形区提供服务。不过，并不总是需要有 3 个扇形区，例如仅需要一个扇形区用来覆盖一条公路。

回到图 1，基地站 B1—B10 均由话音和数据链路与移动通信交换中心(MSC) 20 相连，该交换中心再与公用交换电话网(PSTN)或诸如综合业务数字网(ISDN)等类似设施中的电话局（未图示）相连。移动通信交换中心 MSC 20 和基地站 B1—B10 之间，或者移动通信交换中心 MSC 20 和 PSTN 或 ISDN 之间的相关连接和传输方式都是本领域技术人员所熟知的，可以包括扭绞线对、同轴电缆、光纤电缆或按模拟式或数字式工作的微波无线信道。此外，上述话音和数据链路要以由运营公司提供或从电话公司租借。

继续参见图 1，在蜂窝区 C1—C10 内可以找到多个移动台 M1—M10。尽管图 1 中仅仅示出 10 个移动台，但实际上下移动台的真正数量会大得多，而且总要超过基地站的数量。此外，在某些蜂窝区中可能找不到移动台 M1—M10，在蜂窝区 C1—C10 的某一区中有无移动台 M1—M10 取决于每个移动用户的个人的意愿，他们可以从蜂窝区的某个位置移到另一位置，或者从某一蜂窝区运行到邻近蜂窝区。本技术领域中众所周知，移动台 M1—M10 都包括一发信机、一收信机、一控制器和一用户接口设备，如电话手机。指派给 M1—M10 各移动台一个移动通信标识号(MIN)，此标识号在美国就是移动用户电话号薄号码的数字表示。此 MIN 表明移动用户对无线电通路的订用，并且在呼叫始发时，从移动台送到 MSC

20，在呼叫终接时，从 MSC 20 送到移动台。M1—M10 各移动台还分别用一电子序列号(ESN) 来鉴别，此 ESN 是工厂设定的、无法更改的号码，设计用来防止未经认可就使用移动台。例如，在呼叫始发端，如移动台会把 ESN 送至 MSC 20。该 MSC 就会将收到的 ESN 已与报告被偷盗的移动台的 ESN“黑名单”作比较。若发现有符合的，该偷盗的移动台就会被拒绝入网。

C1—C10 各蜂窝区都从有关政府部门，例如美国的联邦通信委员会(FCC)，指派给整个蜂窝区通信系统的射频(RF)信道中，分到一子集信道。各 RF 信道子集分成若干话音信道和至少一条控制信道（或称播叫/接入信道)，在基地站 B1—B10 和其覆盖范围内的移动站 M1—M10 之间，前者用来载送对讲话音，后来用来载送监管数据消息。各 RF 信道由一基地站和移动台之间的双工信道（双向无线传输通道）组成。RF 包括一对分开的频率，一个用于基地站发射（由移动台接收)，一个用于移动台发射（由基地站接收)。基地站 B1—B10 中的每个信道单元通常工作于分配给相应蜂窝区的射频信道中的一条预选信道上，即信道单元的发信机(TX)和收信机(RX)分别调谐到一对不变的发射和接收频率上。不过，移动台 M1—M10 的收发信机(TX/RX) 可调谐至系统中规定的任意射频信道。

根据容量需要，一个蜂窝区可以有 15 条话音信道，而另一蜂窝区可以具有 100 条以上的话音信通，以及相应的信道单元。然而一般来说，一基地站服务的每个全向蜂窝区或扇形区内仅全有一控制信道，也就是说，为一个全向蜂窝区服务的基地站（图 1)有 1 条控制信道，而为三个扇形服务的基地站（图 2)有 3 条控制信道。本技术领域众所周知，分配给任何给定蜂窝区的 RF（控制和话音）信道可以根据频率重复使用方案再分配给远端的蜂窝区。为了避免射频干扰，相同蜂窝区中的所有射频信道将工作于不同的频率，而且，

任何一个蜂窝区的射频信道将工作在与任何邻近蜂窝区所用的频率都不同的一组频率上。

在空闲状态（不是通话状态）时，M1—M10各移动台调谐至信号最强的控制信道（一般来说即移动台当时所处蜂窝区的控制信道），接着连续监视该信道，并可通过与移动通信交换中心MSC 20相连的基地站B1—B10中相对应的一个基地站接收或发出一电话呼叫。当处于空闲状态下在蜂窝区之间移动时，移动台最终会“失去”与“旧”蜂窝区在控制信道的无线接续，并调谐到“新”蜂窝区的控制信道上。控制信道的起始调谐和变换通过扫描蜂窝区通信系统全部运行中的控制信道自动完成（在美国，每个AMPS系统具有21条“专用”控制信道，即各控制信道的收、发信频率预先确定，且不能改变。这意味着移动台必须扫描最多达21条的信道，以找到“最佳”控制信道）。当找到高接收质量的控制信道时，移动台就保持调谐在该信道上，直到质量又变差。用这种方式，所有移动台总是与该蜂窝区通信系统相“接触”。

在空闲（备用）状态时，M1—M10各移动台连续判断是否在控制信道上收到发给它的播叫消息。例如，一普通（陆上通信线）用户呼叫某一移动用户时，该呼叫立即从PSTN送到分析所拨号码的MSC 20。若所拨的号码被证实，MSC 20就请求某些或全部基地站B1—B10在它们对应的蜂窝区C1—C10内播叫被呼移动台。接收MSC 20请求的B1—B10各基地站接着就在相应蜂窝区的控制信道上传送包含被呼移动台MIN的播叫消息。每个空闲移动台M1—M10就将所监视的控制信道上接收到的播叫消息中的MIN与移动台存储的MIN比较。MIN相符的被呼移动台就在控制信道上发送一播叫应答给基地站，该基地站又将此应答送给MSC 20。

一接收到播叫应答，MSC 20就在发出该播叫应答的蜂窝区中选择一可供使用的话音信道，并请求该蜂窝区的基地站通过控制信

道指令上述移动台调谐到选定的话音信道上(MSC 随时保留着一份其服务区内所有信道的表格，表中包括各信道忙、闲、封锁等状态)。一旦该移动台调谐到选定的话音信道上，便建立直通连接。另一方面，当移动用户发出呼叫，例如通过拨普通用户电话号码，并按其电话手机上的"送出"键时，移动台的 MIN，ESN 和所拨号码就经过控制信道送给基地站，然后又接给 MSC 20。如上文所述，该 MSC 20 证实此移动台，分配一话音信道，再为通话建立直通连接。

若通话状态下移动台在蜂窝区间移动，就会发生呼叫从旧基地站到新基地站的"区间转接"。MSC 在新蜂窝区选择一可供使用的话音信道，然后指令旧基地站在旧蜂窝区中当前的话音信道上将区间转接信息送给移动台，此信息通知移动台调谐到新蜂窝区中选定的话音信道。上述信息以"隐蔽加突发"的方式发送，使通话中断短暂且察觉不到。一旦收到区间转接消息，移动台就调谐到新的话音信道上，并由 MSC 经过新蜂窝区建立直通连接。旧蜂窝区的旧话音信道则在 MSC 中示闲，可用于另一次通话。

除了呼叫始发和播叫应答之外，AMPS 移动台还可接入蜂窝区通信系统进行登记。AMPS 中可进行两类登记：(i)基于时间，更具体地说，基于基地站发送的 REGID ("当前时间") 和 REGINCR 值("登记周期")，以及存储在移动台的 NXTREG 值("叫醒时间") 的周期性登记；(ii) 基于位置，更具体地说，基于正提供服务的蜂窝区通信系统所发送的系统标识的系统地域登记。周期性登记可以用来判断移动台是在工作 (在无线电波覆盖范围内并通电)，还是不在蜂窝区通信系统中。系统地域登记则可以用来判断移动站何时越过边界从一个蜂窝区通信系统到另一个。

一旦在前向控制信道 (基地站至移动台) 上接收到 REGID 信息，若正提供服务的蜂窝区通信系统中允许登记，该移动台就将 REGID值与 NXTREG 值比较，并且将最近一次接收的 SID 值与移

动台最近一次登记的蜂窝区通信系统的SID值比较。如果REGID值大于或等于NXTREG值，表明周期性登记时间已到的话，或者，如果最近一次接收的SID值与最近存储的SID值不同，表明移动台在最近一次成功的登记之后从一个蜂窝区通信系统到达另一个系统的话，移动台就会在后向控制信道（移动台至基地站）上自动送出登记接入消息，并且在前向控制信道上接收到登记确认消息之后，用最近一次接收的REGID值与REGINCR值之和更新NXTREG值（移动台还在每次始发呼叫或播叫应答之后更新NXTREG值）。

上面所述的传统AMPS系统利用频分多路复用(FDM)在话音及控制信道上载送电话通话和控制信息。如上文所述，在此系统各蜂窝区之间划分可供使用的频谱。在每个蜂窝区中，话音（模拟）信号和数据（数字）信号组成至基地站或移动台中发信机的输入信号，该发信机产生与分配给蜂窝区的一个频率相对应的恒频正弦载波，并在发射无线电信号之前，用输入信号调制上述载波的特性(幅度、频率或相位)。此已调载波占据标称中心频率（即未调载波频率）周围较窄的频谱区域（即信道带宽）。一般采用频率调制，使载波频率在任一瞬间都与该瞬间的输入信号的幅度成正比变化(增大或减小)。所形成的已调载波频率在未调（中心）频率周围的偏移一般限制在某一带宽内，例如为30 KHz，以免相邻RF信道重叠和引起相邻信道干扰。

因此，在传统的AMPS系统中，模拟话音信号对用于RF信道上发射的载波加以调制。AMPS系统采用模拟频率调制(FM)，是一种“每载波一信道”(SCPC)系统，即每一RF信道有一话音电路(一对电话用户通话)。但是近期的发展已迎来蜂窝区通信的数字化新时代。提高频谱效率，满足日益增长的系统容量需求。此愿望已经成为模拟转向数字的主要推动力。通过在调制和发射前对若干话音电路的话音进行编码（数字化和压缩）和多路复接，一条RF话音信道

可以由若干数字话音信道共用，而不是仅仅被一模拟话音信道占据。按照这种方式，信道容量，从而整个系统的容量，无需增加话音信道的带宽就可以获得大幅度增加。这样，蜂窝区无线通信系统当然能以值得注意的低成本，例如基地站仅需较少数量的信道单元(收发信机)，为相当大数量的移动台提供服务。而且，数字格式有利于蜂窝区通信系统与正在出现的数字通信网结合。

在美国，电子工业协会(EIA)和通信工业协会(TIA)已经在“走数字化道路”的努力方面领先，并制定了数字蜂窝区通信系统空中接口的临时标准。这一EIA/TIA临时标准即为众人所知的“双式移动台—基地站兼容标准”，并且称为“IS－54”(“IS－54”各种版本的复印件可以从华盛顿特区20006 N.W.宾夕法尼亚街2001号的电子工业协会获得)。术语“双式”是指此系统可工作于模拟式，也可工作于数字式。这种数字式的工作依靠与长期用于陆上通信线电话网中、同时在一实体信道载送多路电话通话的技术相类似的时分多路复用(TDM)技术（对于蜂窝区通信系统还提出过码分多路复用(CDM)，但目前的IS－54－B（B版本）规范采用TDM)。

在有线电话网中，将市内电话用户经分立模拟信道传送至市内电话公司电话局的模拟话音信号连续取样，并对取样幅度进行量化，再按脉冲编码调制(PCM)方法编码成用恒幅脉冲表示的二进制数。将预定数量的PCM信道（即数字话音信道）用一系列的帧传送，每一帧包含各PCM信道的信息猝发段（经编码的取样)。不同PCM信道的猝发段占据诸如铜线设备之类实体信道中所传输各帧中的不同时隙(时间间隔)。最长距离的电话呼叫通过采用TDM的交换体系传输。此项技术还可以应用于在蜂窝区无线通信系统RF信道上的传输。

按TDM运行的RF信道分成一系列重复的时隙，第一时隙包含不同数据源（例如话音信道编码器）的信息猝发段。这些时隙组

合成持续时间预定的一些帧。每一帧的时隙数随该 RF 信道上所要容纳的数学信道数而变化，而此数字信道数又由数字信道的编码速率、RF 信道的调制电平以及带宽给出。帧中的每一时隙一般表示不同的数字信道。因此，RF 信道上每个 TDM 帧的长度即为分配给相同用户的相同数字信道所使用的两个重复时隙之间的最小长度。换句话说，对于每个用户，每个 TDM 帧仅仅包含一个时隙。

根据 IS－54，各数字 TDM RF 信道依照每一数字信道所用话音编码器源速率，可载送 3—6 条数字话音信道（3—6 个电话通话）（在 IS－54 中设定了调制电平和信道带宽）。各数字业务信道（DTC）的话音编码器能以全速率或半速率工作（预计近期会用全速率话音编码器，并一直用到开发出话音质量可接受的半速率编码器）。全速率 DTC 在给定时间中需要比半速率 DTC 多一倍的时隙。在 IS－54 中，每条 TDM RF 信道所载送的可多达 3 条全速率 DTC 或 6 条半速率 DTC。

IS－54 的 TDM RF 信道帧结构示于图 3。TDM RF 信道的每一"帧"包括 6 个相同长度的时隙（1—6），帧的长度为 40ms（每分钟 25 帧）。每条全速率 DTC 使用图 3 帧中的两个等间距时隙，即时隙 1 和 4，或时隙 2 和 5，或时隙 3 和 6。当工作在全速率时，TDM RF 信道可以分配给 3 个用户（A－C），即在图 3 所示"帧"中，用户 A 分到时隙 1 和 4；用户 B 分到时隙 2 和 5；用户 C 分到时间片 3 和 6。因此，对于全速率，每个 TDM 帧实际由 3 个时隙组成而不是 6 个时隙组成，是 20ms 长而不是 40ms 长。每条半速率 DTC 使用图 3 所示"帧"的一个时隙。半速率时，TDM RF 信道可以分配给 6 个用户（A－F），每个用户 A－F 分到图 3 所示帧中 6 个时隙之一。对于半速率，每个 TDM 帧实际由 6 个时隙组成，与 IS－54 中的"帧"定义是一致的。

因此，与基地站和移动台均在 RF 信道上连续发射和接收的模

拟 FDM 蜂窝区通信系统不同，TDM 蜂窝区通信系统以缓冲加突发的不连续传输方式进行运转。各移动台在 RF 信道上所分配的时隙内收、发信号。例如，在全速率的情况下，用户 A 的移动台在时隙 1 发送，在时隙 2 不工作，在时隙 3 接收，在时隙 4 发送，在时隙 5 不工作，在时隙 6 接收，接着重复这一循环(收、发时隙相互错开，无需采用双工电路，否则需要双工电路使移动台的收、发信机可同时工作)。因此，移动台在部分时间(对于全速率为三分之一，对于半速率为六分之一)收、发信号，从而其余时间可以关掉，以节省电力。

然而，目前的IS—54 标准不是全数字标准，而是一种打算在所用移动台由新的双式移动台和全模拟旧移动台混合构成的模拟到数字过渡阶段得到遵守的模拟、数字混合标准。更具体地来说，IS—54 标准是为 AMPS 传统的模拟话音信道和按图 3 所示帧格式组成的数字话音信道这两者提供的。在呼叫建立时，可分配给双式移动台一模拟话音信道(全载波频率)，或者一数字业务信道(载波频率上的一个重复时隙)。单一模拟式移动台则只能分配到一模拟话音信道。

继续需要为现行的单一模拟式移动台提供服务，还导致在 IS—54 中对已有的 AMPS 或类似的 EIA/TIA 553 标准所遗留的模拟控制信道作出规定。根据 IS—54，从基地站到移动台的下行链路的前向模拟控制信道(即播叫信道)按一特定格式载送消息(字)的连续数据流。然而，从移动台到基地站的上行链路的后向模拟控制信道(即接入信道)，即是一种随机出入信道，该信道以争用为基础，用来传送起呼、播叫应答和登记消息。前向控制信道(FOCC)上传送的忙/闲位表示后向控制信道(RECC)当前的状态(可用性)，也就是说，如果该忙/闲位为 0，则 RECC 忙，如果忙/闲位为 1，则 RECC 闲。

IS－54 中规定的 FOCC 格式示于图 4 中。FOCC 上可以传送下列若干不同类型(功能级)的消息：(i)系统参数开销消息(SPOM)；(ii)通用动作开销消息(GOAM)；(iii)登记标识消息，(REGID)；(iv)移动台控制消息，例如播叫消息；(v)控制填充符消息。SPOM、GOAM 以及 REGID 是基地站覆盖范围内的所有移动站都将用到的开销消息。开销消息按称为开销消息序列(OMT)的组进行传送。每个 OMT 的第一消息必须总是每隔 0.8±0.3 秒传送一次的 SPOM。

SPOM 包含有所用蜂窝区通信系统有关信息的两个字，这些信息包括系统标识(SID)和分别表示是否允许归属台和漫游台登记的控制位 REGH 以及 REGR(归属台是工作于订用业务的蜂窝区通信系统的移动台，而漫游台是工作于非订用业务的蜂窝区通信系统的移动台)。GOAM 或 REGID 由一个字组成，并附加在 SPOM 末尾，按需要发送。可按需要将任意数量的通用动作消息附加给 SPOM。通用动作消息的类型包括再扫描播叫信道以及登记递增(REGINCR)消息(REGINCR 和 REGID 二消息控制移动台向提供服务的蜂窝区通信系统进行周期性登记的频率)。发送时 REGID 消息必须附加在 SPOM 上，若有通用动作消息发送，则附加在 OMT 中的最后一个 GOAM 上。

当广播 SPOM、GOAM 和 REGID，以便所有移动台收听前向控制信道(FOCC)时，移动台控制消息(例如播叫消息)就送到某一特定的移动台(特定的 MIN)。移动台控制消息的其它例子还包括模拟话音信道或数字业务信道(全速率或半速率)的分配消息和改变发射功率电平的指令。移动台控制消息由 1 至 4 个字组成。控制填充符消息由一个字组成，无消息在 FOCC 上发送时，总要发送该消息，即用来填充不同消息之间的空隙或多字消息的组间的空隙。

图 4 所示 IS－54 中规定的前向模拟控制信道格式非常不灵活，

因而对于要延长移动台电池寿命等现代蜂窝电话来说不利。具体来说，SPOM 传输的时间间隔是固定的，而且开销以及控制消息附加到 SPOM 上的顺序也是不变的。尽管蜂窝区通信系统可以控制大多数开销消息的传输频率(仅仅需要 SPOM 包含在每个 OMT 中)，但已调谐到 FOCC 的空闲移动台即便当前 OMT 开销消息所含信息可能与先前 OMT 中的相同，也必须重复读出 OMT 中所有的消息，而不仅仅是播叫信息(例外的例子是 GOAM 指令移动台重新扫描播叫信道)。因此，尽管信息与移动台存储器已存储的相同，移动台也频繁更新该存储器。在上述读出周期，耗费电池电力，而未给移动台的运行带来任何相应的好处。

针对已有技术模拟控制信道(ACC)的这些缺点和不足，本发明的目的在于提供一种数字控制信道(DCC)，它可载送与 ACC 上所载送的消息相类似的各种消息，但其中基地站的消息发送频率通常与移动台的消息读出频率无关。换句话说，某些类型的消息可以比其他类型的消息更为频繁地发送，但移动台无需一一读出 DCC 上发送来的消息。

例如，一个刚锁定到 DCC 上的移动台会需要尽快得到当前提供服务的系统的所有相关信息，例如所有权(是不是私营系统?)、服务项目(能否处理某一项特定数据业务?)、系统参数(最大移动台发射功率为多少?)等。因此，这种开销信息可以尽可能经常传送，而不必过分限制 DCC 载送诸如播叫消息等其他消息的容量。但是，这种开销信息大多不经常改变，而且过于频繁地读出这种信息会耗费电池电力。因此，移动台一旦读出开销信息，在收到该信息已变的指示之前，就不再读出。这样就能显著地节约移动台的电池电力。

本发明另一目的在于提供一种 DCC，该 DCC 允许空闲状态的移动台在规定的时间段内从 DCC 读出数量达最低限度的信息，而在所有的其它时间进入“休眠”态。因此，移动台可在返回休眠态之

前尽可能短的时间内读出播叫消息。在休眠态期间，移动台的大多数电子电路关闭，电池电力的消耗为最小。在此情形下，电池寿命可以从例如 13 小时延长至 100 小时，其后才需要对电池充电。读出播叫消息的时间与休眠态时间的比例是可以控制的，并表现为呼叫建立延时与电池功率消耗之间的折衷。

本发明又一个目的在于提供一种灵活的 DCC 格式，该格式适合于一种由“宏”(大半径) 蜂窝区和“微”(小半径) 蜂窝区组成的分层蜂窝区结构。在分层蜂窝区结构中，与目前面向宏蜂窝区的系统相比，移动台更换蜂窝区要频繁得多。重要的是，频繁的蜂窝区选择和再选择不妨碍移动台接收播叫或接通呼叫的能力。本发明通过频繁地发送开销消息，可迅速选择和再选择蜂窝区，同时还提供有效的休眠态运行。开销消息重复频率高，使即将锁定到一新蜂窝区的移动台可迅速寻找播叫信道和接入系统所需的其它参数。

本发明再一个目的在于提供一种调整各蜂窝区 DCC 容量的能力，以满足该蜂窝区的使用要求，即每秒的播叫和接入期望数。

本发明另一个目的在于提供一种 DCC，该 DCC 便于移动通信网融入不断发展的 ISDN 业务范围 (与“ISDN 业务公事包”相结合)。

本发明还有一个目的是提供一种在现行 IS—54 架构内可以方便实施的 DCC。

本发明提供一种在通信信道，例如在蜂窝区通信系统中基地站与移动台之间的数字控制信道，传送信息的方法。此方法包括下列步骤：将信息组成若干信息单元，提供至少一个更改标志以表明至少一个信号单元的值是否已更改，并在通信信道上发送该更改标志和该信息单元。若更改标志表明有更改，就仅仅读出此信息单元。按此方式，发送信息的频率就与读出信息的频率不相关了。因此，收信机可以关闭较长的时间，以减小功率消耗。

在另一方面，本发明提供一种在分成多个子信道的信道上进行信息通信的方法。该方法包括下列步骤：在至少一个子信道上发送信息的至少一部分；在至少一个子信道上发送至少一个更改标志，以表示当时该信息部分更改；接收该信息部分和更改标志，并且响应该更改标志中的指示，读出该信息部分。

本技术领域的技术人员通过参考以下附图，本发明将更好理解，其多种目的和优点将变得更清楚。

图 1 示出传统蜂窝区无线通信系统的结构。

图 2 示出一种可以用于图 1 所示系统中的 3 扇形区蜂窝。

图 3 根据已知的业界标准示出时分多路复用(TDM)射频(RF)信道的帧结构。

图 4 示出该业界标准规定的前向模拟控制信道(ACC)的格式。

图 5 示出可载送至少一条业界标准数字业务信道(DTC)和本发明数字控制信道(DCC)的一 RF 载波 TDM 流的格式。

图 6 示出本发明示例超帧结构。

图 7 示出图 6 所示超帧中全速率 DCC 的结构。

图 8 示出本发明 DCC 开销信息的示例格式。

图 9 示出超帧内 DCC 的示例逻辑信道结构。

图 10 示出图 9 所示 BBCH 的结构。

本发明主要突破点是使开销消息传输频率与移动台读出全部开销信息的要求无关。按照本发明的数字控制信道(DCC)，移动通信系统能以足够高的频率发送开销消息，以充分地为即将锁定到 DCC 上的移动台提供服务，而对 DCC 上已锁定的移动台无消极影响。

在此描述的实施例中，本发明的 DCC 采用时分多路复用(TDM)，因而配置成为一系列具有特定持续时间的时隙(DCC 也可以采用码分多路复用，但为方便这里的描述，假定采用 TDM)。一般来说，任何合适的时隙格式均可以用于实施本发明构思。但从实

际考虑，最好是采用与 IS—54 中定义的数字业务信道（TDC）的格式相兼容的 DCC 格式，也就是说采用长度相等的时隙，每个时隙的持续时间都是 6.66ms（按照 IS—54，3 个时隙 20 ms）。换句话说，DCC 和 DTC 的基本单位将是一个 6.66 mms 的时隙。

既然 DTC 和 DCC 均可以置于相同载波上，本发明在此描述的实施例中选择 IS—54 格式就避免以下两种情形：(i) 基地站和移动台处理两套不同的时隙格式、源编码速率和信令协议（交织、信道编码、同步、检错等），一套为 DCC 而另一套为 DTC，因而所要求的技术复杂；(ii) DCC 必须分开使用另一载波。前一特点有利于迅速地开发和采用工作在 DCC 及 DTC 上的 IS—54 兼容商售产品（基地站和移动台）。后一特点在具备少量载波或者可能仅有一个载波的小蜂窝区的情况下显得尤为重要。

因此，DCC 采用 6.66ms 时隙的合理性在于对兼容性和复杂性的考虑。要能够在相同载波上混合 DCC 时隙和 IS—54 和 DTC 时隙，DCC 时隙持续时间就不得长于 DTC 时隙。从技术复杂性的立足点来看，若 DCC 时隙与 DTC 时隙相等就会简化移动台的设计和测试。在不是不得不需要采用比 DTC 时隙短的 DCC 时隙的情况下，DCC 时隙和 DTC 时隙应该具有相同的持续时间，即为 6.66 ms。

参见图 5，可以看到一载波 TDM 流格式，该载波可以载送至少一条 IS—54 的 DTC 和本发明的 DCC。正如前面所述，IS—54 规定的 DTC 既可以工作在全速率也可以工作在半速率。全速率 DTC 每 20ms 占有 1 个时隙（每 40ms 占用 2 个时隙），而半速率 DTC 每 40ms 占有 1 个时隙。此载波可载送 3 条全速率 DTC 或 6 条半速率 DTC，或两者的任意组合，例如载送 1 条全速率加 4 条半速率的 DTC。

与 DTC 相同，本发明的 DCC 也可以按全速率或半速率工作（对于 DCC 来说，作为与 DTC 的区别，术语“全速率”或“半速率”

均是指所选择的传输速率而不是话音编码器的源速率——一般来说，不论是 DCC 还是 DTC，“全速率”信道每单位时间需要比“半速率”信道多一倍的时隙）。因此，根据加在载波上的 DCC 和 DTC 工作在全速率还是半速率，TDM 流中可有若干可供选择的数字信道（DCC 和 DTC）组合。图 5 示出对某一载波定义的三种可供选择的数字信道组合，即 X、Y 和 Z。

根据方案 X，2 条全速率 DTC（DTC1 和 DTC2）和 1 条全速率 DCC（DCC1）在载波上时分多路复用。方案 X 中，来自 DTC1 的猝发段在时隙 1、4、7、10 等期间发送；来自 DTC2 的猝发段在时隙 2、5、8、11 等期间发送；来自 DCC1 的猝发段在时隙 3、6、9、12 等期间发送。

根据方案 Y，1 条全速率 DTC（DTC1）、2 条半速率 DTC（DTC3 和 DTC4）和 1 条全速率 DCC（DCC1）在载波上时分多路复用。方案 Y 中，来自 DCC1 的猝发段在时隙 1、4、7、10 等期间发送；来自 DTC3 的猝发段在时隙 2、8 等期间发送；来自 DTC1 的猝发段在时隙 3、6、9、12 等期间发送；来自 DTC4 的猝发段在时隙 5、11 等期间发送。

根据方案 Z，1 条全速率 DTC（DTC1）、3 条半速率 DTC（DTC3、DTC4 和 DTC5）和 1 条半速率 DCC（DCC2）在载波上时分多路复用。方案 Z 中，来自 DTC1 的猝发段在时隙 1、4、7、10 等期间发送；来自 DCC2 的猝发段在时隙 2、8 等期间发送；来自 DTC 3 的猝发段在时隙 3、9 等期间发送；来自 DTC4 的猝发段在时隙 5、11 等期间发送；来自 DTC5 的猝发段在时隙 6、12 等期间发送。

本领域普通技术人员不难看出，图 5 中所示的可选方案 X、Y 和 Z 并未列完可对任一可用载波定义的所有数字信道组合。例如图 5 中，方案 X、Y 和 Z 都只定义一条 DCC，而所示出的其它时隙都由 DTC 占用。然而，必须明白可对载波定义一条以上的 DCC（全速率

或半速率)，而且其余时隙的状态（占用或空闲）都取决于该时隙是否用来定义。可以分配给载送电话通话的一条或多条DTC（全速率或半速率）。

一般来说，任一载波所定义的DCC的类型（全速率或半速率）和数量取决于具体应用需要多少控制信道容量。最小的构成单元可以认为是一条半速率的DCC。因此，人们可以从对可使用的载波定义半速率DCC开始。若需要更多的容量，可以由全速率DCC代替半速率DCC。接下来还可以在载波上有1条全速率DCC和1条半速率DCC，再通过增加1条半速率DCC而成为2条全速率DCC，最后载波上可有3条全速率DCC（此时，全部载波用于控制信息，没有留给数字话音信息的容量）。若还要更多的容量，可以从半速率DCC开始，再按前面那样进行对另一载波定义一条或多条DCC。

回到图5，为了达到本发明目的，可以将多个IS－54的连续TDM帧组成一个"超帧"。一般来说，本发明所采用的超帧与IS－54定义的TDM帧之间无需有任何特定的关系。但这里说明的本发明实施例中DCC时隙与IS－54 TDM帧（话音和控制信息交织在同一载波上）内的DTC时隙具有相同结构（长度等)。在IS－54中，TDM的"帧"由6个连续时隙组成，帧长为40 ms。但对于全速率运行。每个用户分配到TDM帧的两个时隙，每20ms一个时隙(对于半速率，每个用户仅分配到该帧的一个时隙)。若将TDM"块"定义为由三个连续TDM时隙组成，其中的第一时隙就与IS－54 TDM帧(图3)的第一或第四时隙相一致，而超帧则由整数个TDM组成，每个TDM块长20 ms。

接下来参见图6，现在可以看到示例超帧的结构。一般来说，超帧可以由任意适当数量的TDM块组成。图6中，超帧由50个TDM块（150个时隙）组成，因此，该超帧的长度为1秒（＝50×20ms)。若采用一条全速率DCC，例如图5中的方案X或Y的话，

每个这样的超帧将包含 50 个 DCC 时隙，即载波上每秒将有 50 个时隙被 DCC 占用。反之，若采用一条半速率 DCC，例如图 5 中的方案 Z 的话，每个这样的超帧将包含 25 个 DCC 时隙。前向 DCC 上每个超帧内至少有某些 DCC 时隙将用来对移动台播叫，即通知空闲移动台来向呼叫。

根据本发明，每个移动台在每个超帧中分配到一个用于接收播叫消息的时隙。因此，超帧可以定义为分配来播叫某移动台的时隙与分配来播叫相同移动台的下一时隙之间的时间。因为很有可能移动台的数量比每个超帧中 DCC 时隙的数量大得多，所以已分配的某一移动台播叫时隙还可以用来播叫共有某种独特特性的其它移动台。更广义地说，超帧还可以定义为分配给相同播叫群的 DCC 时隙之间的时间。

可以采用许多参数中的任意一个来区分各移动台播叫群。例如，若采用移动台识别号(MIN) 来区分播叫群，则可在每个超帧的一个 DCC 时隙发送对 MIN 以数字“0 ”结尾的移动台的播叫消息，在每个超帧的另一个 DCC 时隙发送对 MIN 以数字“1 ”结尾的移动台的播叫消息。

空闲态时，一特定播叫群内的每个移动台在每个超帧的一个时隙期间均被“叫醒”(锁定并读出分配给该移动台所属播叫群的DCC 时隙)，然后查找发给移动台的播叫消息（确定所收到的播叫消息是否包含该移动台的 MIN)，若没有接收到这样的消息，移动台就“返回到休眠状态”(关闭大多数的内部电路以省电)。因此，收听本发明 DCC 上的播叫消息的移动台仅短时间“醒”着，与收听已有技术的 IS－54 模拟控制信道，并连续读出所有控制信息以查找发来的播叫消息的另一种移动台相比，会消耗相当少的电力。

然而，电池电力的节省与呼叫建立的延时（主叫方在接通移动用户之前必须等待的时间）之间要折衷。这种折衷确定移动台“叫

醒”和“查找”DCC 上的播叫消息的频率，换句话说，也就是确定每个超帧的长度。例如，若超帧长 1 秒（图 6），则每个移动台仅“醒”一个时隙的时间，电池用量为全速率时的五十分之一。在这个例子中，对移动台的呼叫平均会延迟 1/2 秒，而最大的延时是 1 秒（呼叫建立的实际延时将取决于与播叫移动台的下一播叫群时隙出现的时间相对的呼叫建立时间）。

将超帧的长度从 1 秒延长到 2 秒，则电力节约加倍，而平均呼叫建立延时从 1/2 秒增加到 1 秒。反之，将超帧的长度从 1 秒减小到 1/2 秒，则电力节约减半，而平均呼叫建立延时从 1/2 秒减小到 1/4 秒。因此超帧的范围包括既有可能是确定大量播叫群来限制休眠态电池消耗的长超帧，也有可能是确定较少量播叫群来限制终接呼叫建立时间的短超帧。

注意到，对节省电池消耗和缩短呼叫建立时间此相互竞争的目标进行平衡的关键是每个超帧中的播叫群(播叫时隙）数量，而不是每个播叫群中的移动台数量。一旦达到平衡，且播叫群的数量确定，则任意播叫群中过多的移动台会出现排队问题。例如，若超帧的长度选为 1 秒，而且对任意播叫群中移动台的呼叫速率大于每秒 1 呼叫，则其中有些呼叫将损失，或者在队列中无限延迟。但这是容量问题，可通过半速率 DCC 变换为全速率 DCC 来解决，或者在有必要时，通过按前面所述的方式和顺序在相同或不同载波上激励另一半速率或全速率 DCC 来解决。

接下来参见图 7，可以看到图 6 所示超帧中的全速率 DCC 的结构。在图 7 中，已将 DCC 时隙从图 6 的超帧中抽出，为了便于说明，使此二图相邻。全速率 DCC 占据超帧的时隙 1、4、7、10…和 148，将按图 5 中的方案 Y 配置。但应该明白，按图 5 中方案 X 配置的全速率 DCC，或按图 5 中方案 Z 配置的半速率 DCC，也都可以用。如图 5 有关解释那样，全速率或半速率 DCC 对载波也可以有几种其它配

置。

继续参见图 7，每个超帧将有许多 DCC 时隙用于播叫，分配给不同的播叫群。但不是每个超帧中的所有 DCC 时隙都会是播叫时隙。至少有某些 DCC 时隙可用来向所有移动台发送开销信息，而其它时隙则可用来向特定的移动台发送数据包。例如，前面 5 个 DCC 时隙（图 7 的时隙 1、4、7、10 和 13）可用来广播开销信息，后面 40 个 DCC 时隙可用于播叫，而超帧的最后 5 个 DCC 时隙可用于数据包。开销消息、寻呼消息以及数据消息只是在 DCC 上可以发送的各种信息的一个例子。

在 DCC 的一个或多个时隙内发送的开销信息包括提供服务的系统的信息和工作在此系统中所需要的移动台性能。该开销信息可包括各种指示，其例子有：(i) 指示移动台分配到播叫时隙；(ii)指示移动台是可收、发通过此基地站的任意呼叫，还是只可收、发紧急呼叫（限制性呼叫）；(iii) 指示用于对此基地站发射的功率值；(iv) 指示系统标识（归属系统或漫游系统）；(v)指示是否采用均衡器（均衡器用于收信机以补偿无线电信道失真和衰减对所发信号的影响）；(vi) 从此基地站接收的 DCC 信号太弱或另外一些原因，例如另一基地站的信号比此基地站的信号强时，可供选择的邻近基地站的 DCC 位置（频率、时隙、超帧的时间偏移）。

根据本发明，当移动台锁定到 DCC 时，该台将首先读出开销信息，以确定系统标识、呼叫限制等，以及(i) 邻近基地站的 DCC 位置（频率、时隙等可找到这些 DCC 的参数），(ii) 超帧中播叫时隙的位置（分配给移动台所属播叫群的 DCC 时隙）。将相关的 DCC 频率存储在存储器中，然后移动台进入休眠态。每个超帧“叫醒”一次，移动台例如每秒“叫醒”一次，以读出分配到的播叫时隙，再返回到休眠态。

休眠态时，移动台基本上不工作，但还有某些任务要执行，例

如，移动台将监视以前存储在存储器的相关 DCC 频率的信号强度。为此，移动台可以周期性地扫描这些频率，并在当时调谐的每个频率上测量信号功率值。要注意，既然该频率的所有时隙发射功率都相同，在测量时该频率上无论发送话音还是数据，任意频率的信号强度测量过程就都相同。

根据本发明，若当前 DCC 信号强度下降到规定值以下，移动台就可以立刻调谐到所监视的 DCC 频率中最好（最强）的那个频率，或调谐到信号比当前 DCC 强一预定值的 DCC 上。这点与现今模拟控制信道(ACC）的运行是有区别的，在模拟控制信道中，“丢失”当前控制信道的移动台必须再扫描系统中所有的专用控制信道(在美国有 21 条信道)，以找出最强的控制信道。

工作在本发明的 DCC 与工作在 IS－54 的模拟信道另一不同点是开销消息的读出。根据 IS－54 ，移动台连续读出 ACC 上在开销消息序列(OMT）中发送的所有开销消息。但根据本发明，移动台在锁定到 DCC 时读出开销消息一次，仅当开销信息改变时才一次一次地读出。这使得必须由移动台读出的开销信息量减到最少，进而使移动台的电池消耗为最小。

接下来参见图 8，可以看到 DCC 上开销信息的示例格式。将开销信息分为不同类的“信息单元”E1、E2、E3，这些单元附加有多个相关“更改标态”F1、F2、F3 等。信息单元包括可以在 DCC 上传送的各类开销消息。每个更改标志代表相应信息单元的指针，也就是说，更改标志 Fi 表示信息单元 Ei 的指针，这里“i”是 1、2、3 等。

移动台不是连续读出信息单元本身，而是以规则的间隔读出信息单元的指针(与之相关的更改标志)。更改标志与相应的信息单元一起发送，移动台可根据更改标志判断是否要读出信息单元。信息单元 Ei 的值改变时将设定相应的更改标志 Fi。当且仅当设定 Fi 时，移动台就必须在休眠态期间读出 Ei（例如，若 Fi 为 1 位，当 Ei 更

改时，Fi 就要置“1”，而所有的其它时间都复位为“0”)。当锁定到一条新 DCC 时，可以要求移动台读出所有信息单元，不论更改标志当时和当前的状态如何。

要注意，图 8 所示的信息单元（开销信息）以规则的间隔重复，将接入系统所需的信息等提供给移动台，特别是即将锁定到 DCC 上的那些移动台。可以通过考虑移动台面临无线电信道干扰的情况下接收信息的速率来确定实际的重复频率(例如在已有技术的模拟控制信道中 SPOM 每 0.8 秒发一次送)。本技术领域众所周知，某些无线电现象，例如瑞利衰落、同信道干扰等，在移动通信环境下会导致所发消息译码差错（误码)。若各类消息以比消息内容更改速率高的速率发送，收信机就有多重机会对发送来的各消息内容进行正确译码（消息发送的频繁程度和消息内容修改的频繁程度有区别)。

在按图 8 所示原则发送的情况下，Fi 和 Ei 会以最小的周期重复，例如每个超帧重复一次，或者每超帧为一秒的话，就每秒重复一次。但由于移动通信环境不尽人意，移动台会无法对特定超帧中所含 Fi 和 Ei 正确译码。若设定此超帧中 Fi 的值(Ei 更改)，移动台就将错过 Ei 值的更改(下一超帧中的 Fi 将复位，在 Ei 再次更改，Fi 再次设定之前，移动台就不会再试图读出 Ei)。

要确保将 Ei 的每次更改通知尽可能多的移动台，系统可以在 Ei 值更改的每个超帧之后的若干超帧内保持设定的 Fi 值。按此方式，如果移动台在 Ei 更改时未读出该 Ei，就至少还有一次机会读出 Ei 新的值。这项技术消除了因失译码失误而丢失新 Ei 值的威胁，但会使移动台重复读出 Ei 的新值，而导致在休眠态运行期间电池电力的不必要浪费。但通过对更改标志的合理配置，能避免上述不良影响。

根据本发明，每个更改标志 Fi 可以由 2 位组成。例如，Fi 的

“00”值可以用来向移动台表示信息单元 Ei 已更改，但不需要读出 Ei。反之，Fi 和“01”值可以用来向移动台表示信息单元 Ei 已更改，并且需要读出。另一方面，Fi 的 11”值可以用来表有条件的读出，即仅当移动台在前一个超帧中丢失 Fi（未能正确译码）时，该台才会读出 Ei。在 Fi 设定为“01”的超帧之后的预定数量的超帧中，更改标志 Fi 设定为“11”。下表列出移动台根据前一个超帧和当前超帧中的 Fi 值所要执行的动作(Fi 栏中的“X ”表示 Fi 错过)：

前一个超帧中的 Fi	当前超帧中的 Fi	读出当前的 Ei
00	00	不执行
01	00	不执行
11	00	不执行
X	00	不执行
00	01	执行
01	01	执行
01	01	执行
X	01	执行
00	11	系统差错
01	11	不执行
11	11	不执行
X	11	执行
X	X	X

如上表所示，不论前一个 Fi 值如何，只要当前 Fi 的值“00”就不读出当前的 Ei，只要当前 Fi 值为“01”就总是读出当前的 Ei。这与仅发送一次 Ei 和 Fi 的场合下，让 1 位的更改标志复位为“0”来表示“不读出”，设定为“1”来表示“读出”是相类似的。在超帧中的 Ei 值已更改时，至少有一个连续的超帧其 Fi 值为“11”，移动台就不会再

读出 Ei。若移动台错过读出前一个 Fi 的值，并且当前的 Fi 值是“11”的话，移动台就读出当前的 Ei，以便顾及错过的 Fi 值是“01”的可能性。

一般来说，更改标志的管理可以由系统话务员控制，但要服从一个条件。若前一个 Fi 值为“00”当前的 Fi 值就不应该为“11”。因为前一个 Fi 的“00”表明前一个 Ei 已更改，而当前的 Fi“11”又表明前一个 Ei 更改，所以“00”之后接“11”的顺序出现内在的矛盾（因此表示为“系统差错”）。除了这种异常情况之外，话务员留有相当大的灵活性。例如在上一表中，表明前一个 Fi 值“01”将后接任意的当前 Fi 值“00”、“01”或“11”。一般来说，要使电池消耗最小，最好是有条件读出都跟在读出之后，也就是说，Fi 值“11”总是跟在 Fi 值“01”之后。然而，如果当前的 Fi 值是“00”或“01”，并且前一个 Fi 值是“01”(而且“01”代表 Ei 新更改)的话，就仅仅意味着移动台将只有一次机会对前一个 Fi 所指示的 Ei 值更改作正确译码。

在实际应用中，让移动台分开其它 Ei 或 Fi 仅只读出某个信息单元 Ei 或某个更改标志 Fi 是不现实的，甚至在技术上不可能，这是因为把许多信息单元或许多更改标志组合在一起用于包括检错(CRC)编码在内的信道编码才更为实际。这样，在实际应用中一组信息单元或更改标志可以为最小的可读出单元。

通过结合 DCC 上的时隙格式对前面提及的兼容性和复杂性给予充分考虑，移动台工作（读出）的最小时间单位最好应该等于一个 DTC 时隙的持续时间。因此，更改标志可以在每个超帧开头的第一个 DCC 时隙（后文称为 FBCCH）内发送，而信息单元可以在该第一时隙的其余部分以及超帧中给定数量的后续 DCC 时隙（后文称为 SBCCH）内发送。

包含更改标志的第一 DCC 时隙(FBCCH)可以由移动台经常读出，到足以使系统话务员可通过更改其它 DCC 时隙(SBCCH)所载

送的信息，动态地调整系统的配置，例如调整即将锁定到 DCC 上的移动站的接入控制参数。对于已经锁定到 DCC 上的移动台来说，FBCCH 控制是否应该读出其它时隙(SBCCH 和 EBCCH)。

利用更改标志使必须由移动台读出的开销消息量最少，无需更多措施，即可达到限制电池消耗的预期目标。此外，本发明还提供一项通过以不同速率发送不同种类开销消息使 DCC 利用效率最高的技术。原则上，各种开销信息可以用相同的速率发送，而不至于损害到限制电池消耗的目的，这是因为即使所有信息按相同速率发送，移动台也只读出更改标志，而不是详细的信息单元（除非它们更改过）。

一般来说，开销信息的传输速率应该足够高，以便使移动台，尤其是即将锁定到 DCC 上的移动台一直随最新的开销信息更新。通过以最频繁更新的开销信息所应发送的速率来发送所有开销信息，可达到上述要求。但是，不需要用这样高的速率发送所有开销信息。实际上，这样做会浪费 DCC 容量，这是为因某些种类的开销信息不如活动性较大的一类开销信息改频繁，可以用较低的速率发送，而不会造成开销信息“过时”。于是，要有效地利用容量，就应该较经常发送频繁更新的各类开销信息，使移动台不停地更新，而较稳定的其它类开销信息应该不常发送。

接下来参见图 9，可以看到一超帧内的示例 DCC 逻辑信道结构。图 9 中，图 7 超帧所示的时隙分配给一组逻辑信道。在前向信道上，这组逻辑信道包括：广播控制信道(BCCH)；至少一条播叫信道(PCH)；单蜂窝区控制信道(SCCH)和至少一条用户数据包信道(UPCH)。但后向 DCC 上的每个时隙都可以为随机接入信道(RCH)。

每条逻辑信道都传送具有某些共同特性或类型相类似的信息流。一条逻辑信道可以按照其分布路径(点到点或点到多点)以及传

输方向（单向或双向）描述其特性。BCCH 是单向、点到多点的信道，所载送开销信息对移动台起到例如可识别系统，识别控制和播叫信道等作用。DCC 的 BCCH 所载送的这类开销信息，在某种程度上与模拟控制信道（ACC）上 OMT 中发送的那类开销消息，例如 SPOM、GOAM 和 REGID 是相对应的。

一般来说，每个超帧会包含分配给不同播叫群的若干条播叫信道（PCH）。各 PCH 都是单向信道，载送专门送至一个移动台或一群移动台（例如车队）的播叫消息。各 SCCH（可以有几条）都是双向、点到点的信道，用于控制单蜂窝区中的一个移动台。UPCH 按术语的严格意义来说并非控制信道，实际上是一种可以用于向各个用户传送包数据（异步数据）的业务信道。RCH 则是单向、点到点信道，用于传送一移动台的起呼、播叫应答以及登记消息。对移动台的答复可以经 SCCH 返回。

图 9 所示的逻辑信道结构（特定的逻辑信道组）和逻辑信道在超帧内的位置都仅仅是示范性的，并未打算包容种种可能的逻辑信道组及其在超帧内的相应信道位置。前向信道上各种逻辑信道组之间最起码的共同点也许是都有 BCCH 和 PCH 。如前文所述，若每条 PCH 在各超帧中占据分配给一特定播叫群的特定时隙，就可以达到限制电池消耗以及有效利用 DCC 容量的双重目标。图 10 中示出达到这些目标的 BCCH 结构。

接下来参见图 10，可以看到图 9 所示的 BCCH 结构。在设计 BCCH 结构的过程中，必须考虑三个主要因素：(i)效率；(ii)系统接入速度；(iii)便携电池经济性。对 BCCH 需传送消息的类别的仔细研究，结果得到一种确定不同类别 BCCH 的设计。这些 BCCH 类别可以参照移动台需读出这些信道所载送信息的速率来确定。

BCCH 上可以载送若干种信息。例如，BCCH 可以载送以下种类的信息。(i)随机接入控制参数和认证参数（认证是系统证实移动

台有效性的过程，反之亦然)；(ii)终端用户普遍感兴趣的消息（例如移动台附近的交通事故)；(iii)邻近蜂窝区 DCC 的有无、位置（频率、时隙等)以及某些特征；(iv)提供服务的系统和蜂窝区的标识以及它们的服务能力。

信息内容的更改速率以种类“(i)”的消息为最高，种类“(iv)”的消息为最低。换句话说，通常更改速率按种类“i”到种类“iv”的上升顺序而下降。此外，消息长度在各种类之间也会变化。例如，种类(ii)的消息可以相当长（IS－54 中规定为几个字)，但它们零星发送。因此，不仅不同种类的信息单元以不同速率更改，而且 BCCH 上所要发送的信息总量也以无法预知的方式随时间而变化。于是必须在 BCCH 中对内容以不同速率改变且长度不同的各种消息作出规定。

前向 DCC 上有 BCCH、PCH，可能还有如图 9 所示的其它种类的逻辑信道。前向 DCC 上的超帧可以定义为分配给相同播叫群的某一 BCCH 到下一 BCCH，或某一 PCH 到下一 PCH 的重复时间。每个 PCH 一般只载送一种消息，即播叫消息，而且最好每个超帧只分配一个时隙，使电池消耗为最小。另一方面，BCCH 可以载送不同长度的各种消息，还可以分配到每个超帧中数量固定的时隙，或根据瞬时容量需要，即任意时刻所要发送的 BCCH 消息的数量和长度，分配到超帧之间各不相同的数量动态变化的时隙。

至少两方面因素支持将数量固定而不是数量动态变化的时隙分配给每个超帧的 BCCH。首先，超帧之间 BCCH 时隙数量的改变使得移动台读出 BCCH 时隙的操作变得复杂（将会要求移动台连续判断每个超帧中的哪些时隙分配给 BCCH)。其次，BCCH 时隙的动态分配会导致 PCH 容量的浪费，这是因为，要么每个超帧得有大量时隙为 BCCH 保留，以应付最坏的情况（可能的最长 BCCH 消息)，每个超帧就剩下较少的 PCH 时隙；要么每个超帧保留较少数量的

时隙，在这种情况下，不管何时需要发送长的 BCCH 消息都得废弃邻接的 PCH 时隙。

要避免选择 BCCH 时隙动态分配会浪费 PCH 容量，可以为 BCCH 保留少量时隙，不论何时要发送长的 BCCH 消息，分配到邻接 PCH 播叫时隙的移动台都可以再分配到该超帧的其它 PCH 时隙。但是，改变超帧中 PCH 时隙(播叫群)的数量需要在休眠态期间叫醒受影响的移动台重新分配，这与限制电池消耗的目标不符。因此，BCCH 时隙动态分配必须为坏的情况设计，在这种情况下，BCCH 时隙常常(除了必须发送长消息以外的全部时间)由无用的控制填充符填充而不是有用的控制信息。

总之，各个超帧分配数量固定的 BCCH 时隙胜过动态分配。可以由蜂窝区通信系统的话务员选择每个超帧中 BCCH 时隙的实际数量，以满足使用的需要（所选数量 BCCH 时隙将在 DCC 上传送到移动台）。但是，不论每帧多少时隙用于 BCCH，应该要求移动台在休眠态期间读出尽可能少的 BCCH 信息（时隙），以便电池消耗为最小。为达到此目的，BCCH 可以组成如图 8 所示的许多信息单元及其相关的更改标志。

这些更改标志可以插入移动台以某一最小频率（例如每个超帧一次或每秒一次)读出的一 BCCH 部分。因为这部分频繁地由移动台读出，对于有效的休眠态运行来说，该部分应尽可能小。一般来说，这部分可以是长度小于或等于一个时隙的任意单位时间。但为了简化移动台的读出，可以使这部分等于一个 BCCH 时隙。该时隙称为“快速”BCCH(FBCCH)，每个超帧重复一次。信息单元可以插入 FBCCH 中未被更改标志占据的任何部分以及后续 BCCH 时隙中。这些后续时隙可以与 FBCCH 相邻或者分离，还可以组成一个或多个逻辑信道。

考虑不同种类信息的频谱后可知，经常被读出的 FBCCH 可以

用来发送频繁更新的信息。为了避免重复读出不是频繁更新的信息，这种信息可以在其它 BCCH 信道中传送。移动台可以从 FBCCH 获得更改标志以及这些其它 BCCH 信道在超帧中的位置信息（有多少时隙分配给这些信道，信道的起始位置等），因此，FBCCH 可指示何时何处读出信息单元。

某些信息必须在每个超帧中传送，以便移动台可读出超帧中的其它信息，或者可在第一次锁定到 DCC 时迅速找到提供最佳服务的蜂窝区。例如，移动台必须在读出 DCC 低层结构的某些基本信息后，才能读出超帧中的其它信息。这种基本信息所含内容的例子为：超帧开始指示；超帧时间（DCC 时隙数量），DCC 是半速率还是全速率；DCC 格式（TDM 块中时隙 1、2 或 3 中的哪个时隙）；其它 BCCH 信道的位置；所分配 PCH 的位置；移动台收信机是不是应该用均衡器。其它种类的信息也应该经常发送，以便移动台能迅速地接受或拒绝一特定的 DCC。例如，每个超帧器发送蜂窝区可用性以及数据处理能力的信息（蜂窝区可能仅仅是封闭用户群可用，或无法处理移动台的数据传输）、系统标识和蜂窝区标识等。

一般来说，至少某些系统接入所需要的信息可以在每个超帧中读出的 FBCCH 中传送（假定插入更改标志后 FBCCH 仍留有足够的空间）。这允许即将锁定到 DCC 上的移动台可迅速找到所需的信息，例如用来收、发呼叫的信息等。但在锁定到 DCC 后，移动台将不再需要读出这种信息，除非这种信息更改。因而对于有效的休眠态工作而言，若非全部至少是大多数这种信息可以不在 FBCCH 中传送，而在称为“慢”BCCH（SBCCH）的另一 BCCH 子信道中传送。与 FBCCH 一样，SBCCH 以最小的周期（例如以每一超帧）重复，并在每个超帧中分配数量固定的时隙（SBCCH 中时隙的数量和位置可以在 FBCCH 中指示）。但是与 FBCCH 不同，SBCCH 不是每次传送都读出，而仅仅在 FBCCH 中相关更改标志设定时才读出（除了

在系统接入以前可以读出 SBCCH 一次以外)。

在进行 DCC 上的锁定时，移动台可以自动读出 SBCCH。若每个超帧为 1 秒长，移动台平均必须等待半秒种以读出 SBCCH 中的信息。但在无线通信环境中，同信道干扰和瑞利衰落会使所接收的头几个超帧产生误码，或者移动台无法立刻与一开始所接收的超帧同步，而与后面的超帧同步，所以读出(译码)SBCCH 的真正平均等待时间实际上比半秒钟长。但是在锁定长 DCC 上，并且读出一次 SBCCH 中的信息单元以后，移动台将不再读出任何信息单元，直到 FBCCH 中的相应更改标志要求这么做。

讨述至此的 FBCCH 和 SBCCH，每超帧均采用数量较少的时隙，并足以适应有效的休眠态工作以及快速蜂窝区选择(每条 FBCCH 和 SBCCH 的时隙数量固定，但由系统控制)的需要。还需要一种机制以便在 BCCH 上发送长的开销消息。为达到此目的，引入称为“延伸”BCCH (EBCCH)的第三种 BCCH 信道。

EBCCH 每个超帧同样分配到系统控制的固定数量时隙，但 EBCCH 上发送的长消息可以延伸(持续)几个超帧，因此，每个超帧中 EBCCH 时隙的数量可能比载送长消息所需的时隙数量少得多。换句说话，不论消息长短，每个超帧中 EBCCH 时隙的数量是固定的。若超帧中没有足够的 EBCCH 时隙适应所有的 EBCCH 消息，就采用后续的超帧。可以经 FBCCH 或 SBCCH 通知移动台分配给每个超帧的 EBCCH 的数量和位置。在当前 FBCCH 或 SBCCH 中可以发送一 EBCCH 标志的开头，以通知移动台当前超帧包含 EBCCH 消息的开头。

借助 BCCH，长信息和/或零星信息可以在 DCC 上传送，而不危及超帧的组织，如 PCH 的分配，或者 DCC 的容量等。例如，可以在 EBCCH 上传送邻近基地站 DCC 表。该表所含信息规模相当大，需要几个时隙，它们可以分布在几个超帧的 EBCCH，而不是占据一

个超帧的很大部分。

因此，根据本发明，BCCH 分为三种逻辑子信道，即 FBCCH、SBCCH 和 EBCCH，至少两种(SBCCH 和 EBCCH)可以用来传送不同种类的信息。一般来说，SBCCH 载送长度可预测或预定的消息。EBCCH 为发送可变长度消息提供附加灵活性。FBCCH、SBCCH 和 EBCCH 可以是一个超帧中的连续块。

FBCCH 含有通知移动台是否要在 SBCCH 和 EBCCH 中读出信息单元的更改标志。作为替换，FBCCH 可以包含 SBCCH 中信息单元的更改标志，SBCCH 可以包含 EBCCH 中信息单元的更改标志。移动台以最小的周期读出 FBCCH。在接入系统之前，可以至少读出一次 SBCCH。也可以至少读出一次 EBCCH。当进行 DCC 上的锁定时，移动台可以读出 FBCCH、SBCCH 和 EBCCH 中的全部信息。一旦锁定到 DCC 上，移动台在休眠态期间每帧仅读出 FBCCH 和分配到的 PCH，除非有更改标志表明移动台还应该读出 SBCCH 和/或 EBCCH 中的信息单元。

应该指出的是更改标志的位置在不同的应用中可以改变。例如，SBCCH 的更改标志(也可能是 EBCCH 的)可以置于分配到的 PCH 中，在这种情况下移动台可以在休眠态期间仅读出分配到的 PCH，而不读出 FBCCH 和分配到的 PCH 两者(EBCCH 的更改标志可以置于分配到的 PCH 中或 SBCCH 中)。实际上，FBCCH 可以完全不用，或者如果保留 FBCCH，则 PCH 除 SBCCH（还可能是 EBCCH）的信息单元更改标志外，还可以包含 FBCCH 的信息单元更改标志。在另一种变形中，FBCCH 和分配到的 PCH 都有多份 SBCCH（还可能是 EBCCH)更改标志。后一方法对当前没有分配 PCH 的移动台（例如工作在 UPCH 上的移动台)有利。

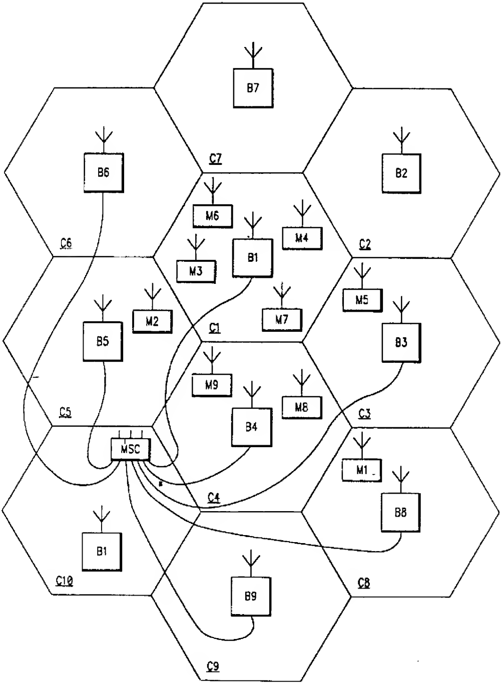
还应该指出的是，由于消息在 DCC 上安排格式的方法，移动台无法独立于所有其它信息单元读出任意一种信息单元(Ei)，但至

少必须读出组合和编码在一起后插入 FBCCH、SBCCH 或 EBCCH 的一个时隙的一组信息单元。在这种情况下，每个更改标志将不是指出单个信息单元，而是指出可以占据一 FBCCH、SBCCH 或 EBCCH 时隙的部分或全部，甚至于整个 FBCCH、SBCCH 和/或 EBCCH 信道（例如 BCCH 的全部)的一组信息单元。因此，根据消息的格式安排，一更改标志可以表示，移动台是否应该按照适当的情况，分别读出一个信息单元、一组信息单元、整个时隙或者是 FBCCH、SBCCH 和/或 EBCH 的全部。

在此详细论述的本发明实施例中，采用的是某种时隙、帧、超帧以及信道格式。但是本发明的构思同样适用于普通技术人员所采用的其它格式。另外，在此叙述的实施例的蜂窝区无线通信系统采用时分多路复用技术。但应该清楚，本发明的构思，例如指针技术（更改标志)和开销信息(BCCH)的划分，对于包含采用频分多路复用(FDM)或者码分多路复用(CDM)技术的蜂窝区无线通信系统在内、无限制的任何无线通信系统起着同等作用。

因此，前面的详细说明只表示本发明的某个特定的实施例。本领域技术人员将会知道，在不脱离在此说明的本发明实质和保护范围的前提下，可以作出许多修改和变形。因而应该清楚，在此说明的本发明的形式仅是示范性的，无论如何也不能用于限定如后面权利要求所确定的本发明保护范围。

说 明 书 附 图



B7
C7
B6
B2
M6
M4
B1
M3
C6
C2
M5
M2
M7
B5
C1
B3
M9
M8
C5
B4
C3
MSC
M1
B8
C4
B1
B9
C10
C8
C9

图 1

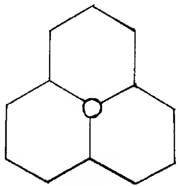


图 2

1 帧 = 40 ms

	时隙 1	时隙 2	时隙 3	时隙 4	时隙 5	时隙 6
全速率	A	B	C	A	B	C
半速率	A	B	C	D	E	F

图 3

0.8s

SPOM	GOAM	REGID	播叫和控制填充符	SPOM

图 4

DTC1 = 全速率
DTC2 = 全速率

DTC3 = 半速率
DTC4 = 半速率
DTC5 = 半速率

DCC1 = 全速率
DCC2 = 半速率

TDM 帧 = 40ms

TDM 块 = 20 ms

	时隙 1	时隙 2	时隙 3	时隙 4	时隙 5	时隙 6
X	DTC 1	DTC 2	DCC 1	DTC 1	DTC2	DCC 1
Y	DCC 1	DTC 3	DTC 1	DCC 1	DTC 4	DTC 1
Z	DTC 1	DCC 2	DTC 3	DTC 1	DTC 4	DTC 5

时间 --->

时隙 7	时隙 8	时隙 9	时隙 10	时隙 11	时隙 12	...
DTC 1	DTC 2	DCC 1	DTC 1	DTC 2	DCC 1	
DCC 1	DTC 3	DTC 1	DCC 1	DTC 4	DTC 1	
DTC 1	DCC 2	DTC 3	DTC 1	DTC 4	DTC 5	

图 5

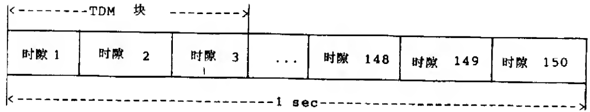

TDM 块
时隙 1
时隙 2
时隙 3
...
时隙 148
时隙 149
时隙 150
1 sec

图 6

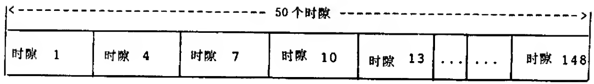

50个时隙
时隙 1
时隙 4
时隙 7
时隙 10
时隙 13
...
...
时隙 148

图 7

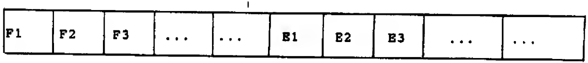

F1
F2
F3
...
...
E1
E2
E3
...
...

图 8

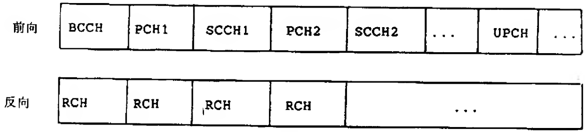

前向
BCCH
PCH1
SCCH1
PCH2
SCCH2
...
UPCH
...
反向
RCH
RCH
RCH
RCH
...

图 9

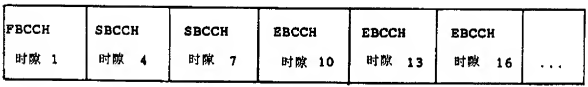

FBCCH
时隙 1
SBCCH
时隙 4
SBCCH
时隙 7
EBCCH
时隙 10
EBCCH
时隙 13
EBCCH
时隙 16
...

图 10

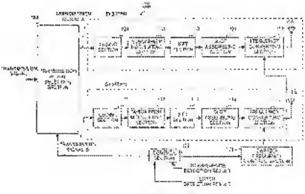
Radio transmission apparatus and radio communication method

Patent number: CN1489836 (A)
Publication date: 2004-04-14

Inventor(s): KIMIHIKO ISHIKAWA [JP] +
Applicant(s): MATSUSHITA ELECTRIC IND CO LTD [JP] +

Classification:
- international: *H04B7/06; H04B7/12;* H04B7/02; H04B7/04; (IPC1-7): H04B7/06
- european: H04B7/06C; H04B7/12
Application number: CN20028004161 20021030
Priority number(s): JP20010334392 20011031

Abstract not available for CN 1489836 (A)
Abstract of correspondent: **EP 1363410 (A1)**
Translate this text



There is provided a radio transmitting apparatus capable of improving spectrum efficiency and a transmission rate while maintaining communication quality. The present apparatus adaptively selects space multiplex where different information (transmission signal A NOTEQUAL transmission signal B) is transmitted from a plurality of antennas with the same frequency, frequency multiplex where different information (transmission signal A NOTEQUAL transmission signal B) is transmitted from the plurality of antennas with different frequencies, space diversity where the same information is transmitted from the plurality of antennas with the same frequency, and frequency diversity where the same information (transmission signal A = transmission signal B) is transmitted from the plurality of antennas with different frequencies according to circumstances of a propagation path.

CN1489836A Radio transmission apparatus and radio communication method

Bibliography

DWPI Title
Radio transmitter switches between transmission of different data with identical or different frequency and transmission of identical data with identical or different frequency, based on transmission path condition

English Title
Radio transmission apparatus and radio communication method

Assignee/Applicant
Standardized: **MATSUSHITA ELECTRIC IND CO LTD** .

Inventor
KIMIHIKO ISHIKAWA

Publication Date (Kind Code)
2004-04-14 (A)

Application Number / Date
CN2002804161A / 2002-10-30

Priority Number / Date / Country
JP2001334392A / 2001-10-31 / JP
CN2002804161A / 2002-10-30 / CN

[19] 中华人民共和国国家知识产权局

[51] Int. Cl⁷
H04B 7/06

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[71] 申请人 松下电器产业株式会社

地址 日本大阪府

[72] 发明人 石川公彦

[74] 专利代理机构 北京市柳沈律师事务所

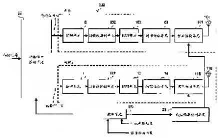
代理人 吕晓章 马 莹

权利要求书1页 说明书7页 附图6页

[54] 发明名称 无线发射装置和无线通信方法

[57] 摘要

一种无线发射装置，能够进一步改善频率使用效率和传输速率，同时保持通信质量。在该装置中，根据传输路径条件来自适应地进行选择：用来自多个天线(106、116)的相同频率来传输不同的信息(传输信号A≠传输信号B)(空间复用)；用来自多个天线(106、116)的不同频率来传输不同的信息(传输信号A≠传输信号B)(频率复用)；用来自多个天线(106、116)的相同频率来传输相同的信息(传输信号A=传输信号B)(空间分集)；用来自多个天线(106、116)的不同频率来传输相同的信息(传输信号A=传输信号B)(频率分集)。



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1. 一种无线发射装置，包括:

发射装置，使用多个天线来发射相同或不同的信息;

测量装置，用于测量传播路径的情况；以及

控制装置，根据由所述测量装置所测量的传播路径的情况，来控制多个天线的每个发射频率和从多个天线发射的信息数量。

2. 如权利要求1所述的无线发射装置，还包括用于检测未分配给其他用户的频率的检测装置，其中所述控制装置根据由所述检测装置所检测的频率来设置多个天线的每个发射频率。

3. 如权利要求1所述的无线发射装置，其中，当由所述测量装置测量的传播路径的情况良好时，所述控制装置将多个天线的每个发射频率设置为相同的频率，以便从多个天线发射不同的信息。

4. 如权利要求1所述的无线发射装置，其中，当由所述测量装置测量的传播路径的情况差时，所述控制装置将多个天线的每个发射频率设置为不同的频率，以便从多个天线发射不同的信息。

5. 如权利要求1所述的无线发射装置，其中，当由所述测量装置测量的传播路径的情况差时，所述控制装置将多个天线的每个发射频率设置为相同的频率，以便从多个天线发射相同的信息。

6. 如权利要求1所述的无线发射装置，其中，当由所述检测装置测量的传播路径的情况差时，所述控制装置将多个天线的每个发射频率设置为不同的频率，以便从多个天线发射相同的信息。

7. 一种无线基站装置，包括根据权利要求1的无线发射装置。

8. 一种无线终端装置，包括根据权利要求1的无线发射装置。

9. 一种无线通信方法，包括步骤:

使用多个天线来发射相同或不同的信息;

测量传播路径的情况；以及

根据由所述测量步骤测量的传播路径的情况，来控制多个天线的每个发射频率和从多个天线发射的信息数量。

无线发射装置和无线通信方法

技术领域

本发明涉及一种在数字无线通信系统中使用的无线发射装置和无线通信方法。

背景技术

目前正在进行针对世界范围统一标准的宽带无线接入系统的准备。而且，对于下一代，期望建立充分使用接近亚毫米波带的丰富的频率资源的移动宽带无线接入系统。

作为目前的宽带无线接入系统，在所使用的一种系统中调制方法是在世界范围统一标准下使用 5GHz 的频带的正交频分复用（OFDM），并且根据传播路径的情况来自适应地控制对应于每个副载波的调制多值数量。根据这种方法，在好的传播路径情况下，能够获得一个大的调制多值数量。为此，能够获得使用例如 20MHz 的频带中的 64 - 值 QAM 的 54Mbps 的传输速率。

最近几年，为了改善频率的有效使用，已经考虑了 SDM（空分复用）方法的应用，在 SDM 方法中，使用多个天线用相同的频率来执行空分复用（“宽带移动通信系统的 PDM-COFDM 方案”，Sugiyama，Umehira，电子、信息和通信工程学会，通信协会，2001，SB-3-7）。在这种类型的方法中，调制与常规情况下的调制相同，但是用相同的频率从多个天线发射不同的信息来执行空间复用。为此，例如，在使用两个天线的情况中，传输容量加倍而不会增加将使用的频带，因此也加倍了传输速率。

然而，在上述的常规方法中，存在这样一种情况：根据来自另一个小区的干扰和传播路径的情况，原则上接收方不能执行受到空间复用的传输信号的分离和再现。为此，不能一直增加通信容量，并且存在这样一种可能性，即，将发生不能满足预期的传输速率的需要的这样一种情况。另外，有这样一种可能，根据这种情况将发生通信不可能状态。

发明内容

本发明的一个目的是提供一种无线发射装置和无线通信方法，其能够改

善频频谱效率和传输速率，同时保持通信质量。

本发明的实质是：当使用多个天线来发射相同或不同的信息时，根据传播路径的情况来控制多个天线的每个发射频率和从多个天线发射的信息数量，即，自适应地选择使用相同频率从多个天线发射不同信息的空间复用、使用不同频率从多个天线发射不同信息的频率复用、使用相同频率从多个天线发射的相同信息的空间分集，以及根据传播路径的情况使用不同频率从多个天线发射的相同信息的频率分集。

附图说明

图 1 示出了根据本发明一个实施例的无线发射装置的结构方框图；

图 2 示出了执行与图 1 所示的无线发射装置无线通信的无线接收装置的结构方框图；

图 3 示出了能够由图 1 所示的无线发射装置执行的无线通信系统的空间复用的图；

图 4 示出了能够由图 1 所示的无线发射装置执行的无线通信系统的频率复用的图；

图 5 示出了能够由图 1 所示的无线发射装置执行的无线通信系统的空间分集的图；和

图 6 示出了能够由图 1 所示的无线发射装置执行的无线通信系统的频率分集的图。

具体实施方式

将参考附图具体解释本发明的一个实施例。

图 1 示出了根据本发明一个实施例的无线发射装置的结构方框图，以及图 2 示出了执行与图 1 所示的无线发射装置无线通信的无线接收装置的结构方框图。图 1 示出的无线发射装置和图 2 示出的无线接收装置能够被安装在相同的无线通信装置中。

这种无线通信装置是一种 OFDM 无线通信装置，图 1 中示出的无线发射装置是对于 OFDM 信号的发射器，图 2 中示出的无线接收装置 200 是对于 OFDM 信号的接收器。由于通过多载波转换和保护间隔插入在高速数字信号发射中能够减小多路延迟扩展的影响，所以需要注意作为下一代的移动宽带

无线接入的 OFDM。这里，OFDM 信号是通过对多个正交副载波信号进行多路复用而获得的信号。

根据本实施例，当使用 OFDM 中的多个天线来发射相同或不同的信息时，根据传播路径的情况来控制多个天线中的每个的发射频率以及从多个天线发射的信息数量，从而改善频率使用效率和传输速率，同时保持了通信质量。下文将解释作为一个示例的天线数量是二的一种情况。

图 1 所示的无线发射装置(发射器)100 包括发射传输信号 A 的系统 1 以及发射传输信号 B 的系统 2。系统 1 包括编码单元 101、副载波调制单元 102、逆快速傅里叶变换(IFFT)单元 103、时隙组合单元 104、频率转换单元 105、天线 106。系统 2 包括编码单元 111、副载波调制单元 112、逆快速傅里叶变换(IFFT)单元 113、时隙组合单元 114、频率转换单元 115、天线 116。而且，发射器 100 包括载波频率控制单元 121、传输信号选择单元 122、和用于整体的控制单元 123。

同时，图 2 所示的无线接收装置(接收器)200 包括：系统 1，接收来自发射器 100 的传输信号 A，以便获得所接收的信号 A；和系统 2，接收来自发射器 100 的传输信号 B，以便获得所接收的信号 B。然而，当传输信号 A 和传输信号 B 具有相同频率时，在每个系统接收传输信号 A 和传输信号 B。系统 1 包括天线 201、频率转换单元 202、逆快速傅里叶变换(FFT)单元 203、副载波解调单元 204、以及解码单元 205。系统 2 包括天线 211、频率转换单元 212、逆快速傅里叶变换(FFT)单元 213、副载波解调单元 214、以及解码单元 215。而且，接收器 200 包括载波频率控制单元 221、符号同步定时单元 222、干扰补偿单元 223、干扰检测单元 224、以及误差检测单元 225。

此外，当无线发射装置 100 和无线发射装置 200 被安装在相同的无线通信装置上时，发射器 100 的天线 106 和 116 以及接收器 200 的天线 201 和 211 可以是发射和接收共享类型。

下一步将解释上述结构的发射器 100 和接收器 200 的各自操作。

首先，下面将描述发射器 100 的操作。

例如，系统 1 的传输信号 A 通常是由编码单元 101 编码的。对于每个副载波，由副载波调制单元 102 来调制所编码的信号，并在其后将该结果输出到 IFFT 单元 103。IFFT 单元 103 对副载波调制单元 103 的一个输出信号进行逆快速傅里叶变换(IFFT)，以便产生一个 OFDM 信号。通过时隙组合单元 104，

将保护间隔和前同步信号插入已产生的OFDM信号，之后将结果输出到频率转换单元105。频率转换单元105将时隙组合单元104的一个输出信号上变频为一个无线频率(传输频率)，该频率由载波频率控制单元121独立控制。上变频的传输信号通过天线106发射。而且，对系统1的传输信号A进行与系统2的传输信号B同样的处理，频率转换单元115将时隙组合单元114的一个输出信号上变频为一个无线频率(传输频率)，该频率由载波频率控制单元121控制独立，并且之后从天线116发射结果。这时，通过传输信号选择单元122来选择是否系统1的传输信号A和系统2的传输信号B被设置为相同或不同。通过控制单元123来自适应地控制载波频率控制单元121和传输信号选择单元122。由控制单元123做出的自适应控制的内容将在后面具体描述。

下面将描述接收器200的操作。

通过频率转换单元202使用无线频率(与发射传输信号A的天线106的传输频率相同的频率)来下变频经系统1的天线201接收的OFDM信号，该无线频率由载波频率控制单元221独立控制，并且之后经保护间隔移除单元(未示出)将结果输出到FFT单元203。使用从符号同步定时单元222输出的定时信号，FFT单元203对受到保护间隔移除的OFDM信号进行快速傅里叶变换(FFT)。对经系统2的天线211接收的OFDM进行相同的处理。通过频率转换单元212使用一个无线频率(与发射传输信号B的天线116的传输频率相同的频率)来下变频OFDM信号，该无线频率不受载波频率控制单元221的控制，并且之后从其中移除保护间隔，并进行FFT处理。干扰补偿单元223估计天线201和211之间的传递函数，以便分离受到空间复用的信号。在系统1和系统2中，对于每个副载波，通过副载波解码单元204和214对所分离的信号进行解码。从而获得所接收的信号A和所接收的信号B。

这时，干扰测量单元224测量每一系统的干扰电平，并检测干扰波的存在和缺少，从而根据多个可用的频率来检测未分配给其它用户的频率。而且，误差检测单元225检测一个作为指示传播路径情况的基准的误码率(例如，BER(位误码率)等)，经安装在相同无线通信装置上的发射器(未示出)和安装在通信另一端的无线通信装置的接收器(未示出)，将由干扰检测单元224执行的干扰检测结果(每个系统的干扰波的存在或不存在)以及由误差检测单元225执行误差检测结果(每个系统的误码率)传输到通信另一端的发射器100的控

制单元 123。

参考图 3 到 6，接下来给出在发射器 100 的上述自适应控制的内容的解释。另外，在下文解释作为示例的使用包括信道 1(CH1)到信道 4(CH4)的四个信道(频带)的情况。而且，在图 3 到 6 中，天线＃1 表示系统 1 的天线 106，天线＃2 表示系统 2 的天线 116。

在这个实施例中，发射器 100 能够使用四个无线通信系统。第一种情况是空间复用情况，即，一种用相同频率(例如图 3)从两个天线 106 和 116 发射不同信息(传输信号 A≠传输信号 B)的情况。第二种情况是频率复用情况，即一种用不同频率(例如图 4)从两个天线 106 和 116 发射不同信息(传输信号 A≠传输信号 B)的情况。第三种情况是空间分集情况，即，一种用相同频率(例如图 5)从两个天线 106 和 116 发射相同信息(传输信号 A＝传输信号 B)的情况。第四种情况是频率分集情况，即，一种用不同频率(例如图 6)从两个天线 106 和 116 发射相同信息(传输信号 A＝传输信号 B)的情况。根据来自安装在相同无线通信装置上的接收器 200 的干扰检测结果(每个系统的干扰波的存在或缺少)和误差检测结果(每个系统的误码率)，控制单元 123 在这四种无线通信方法中进行自适应地切换。

具体地，例如，当误差检测结果良好时，即传播路径的情况良好，如图 3 所示，用相同的频率从两个天线 106 和 116 发射不同的信息(传输信号 A≠传输信号 B)，从而执行空间复用。在图 3 示出的示例中，避免了存在干扰波的 CH1、CH2、CH4，即分配到其它用户的频率(信道)，并且不同的传输信号 A 和 B 被复用，并使用空闲的相同信道(CH3)分别从系统 1 的天线 106 和系统 2 的天线 116 被发射。另外，这时，接收器 200 使用由发射器 100 使用的频率(图 3 的示例中的 CH3 的频率)来执行接收操作。

根据该方法，当传播路径的情况良好时，执行空间复用，因此能够将频谱效率和传输速率进一步改善到最大程度，而不会增加将被使用的频率，即同时保持要使用的频率。此外，根据多个(这种情况中是四个)可用的频率(CH1 到 CH4)来检测不带频率波的频率，并且根据所检测的频率来设置多个天线(这种情况中是二个)的每个的传输频率。为此，频谱效率和传输速率能够进一步改善，而没有来自其它用户的干扰的影响，即同时保持通信质量。

而且，例如，当误差检测结果差时，即传播路径的情况差，如图 4 所示，用不同的频率从两个天线 106 和 116 发射不同的信息(传输信号 A≠传输信号

B),并且从而执行频率复用。在图 4 示出的示例中,避免了存在干扰波的 CH1、CH4，即，分配到其它用户的频率(信道)，使用空闲信道 CH2 和 CH3 中的一个信道(CH2)从系统 1 的天线 106 发射传输信号 A，并且使用与系统 1 不同的另一信道(CH3)从系统 2 的天线 116 来发射不同于系统 1 的传输信号 B。另外，这时，接收器 200 使用由发射器 100 使用的每个系统的频率(图 4 示例中系统 1 使用 CH2 的频率和系统 2 使用 CH3 的频率)来执行接收操作。

根据该方法，当传播路径的情况良好时，执行频率复用，因此能够进一步改善谱频率和传输速率，由于每个系统的空间复用而没有通信质量恶化的影响，即，同时保持通信质量。此外，根据多个(这种情况中是四个)可用的频率(CH1 到 CH4)来检测没有频率波的频率，并且根据所检测的频率来设置多个天线(这种情况中是二个)的每个的传输频率。为此，频谱效率和传输速率能够进一步改善，而没有来自其它用户的干扰的影响，即同时保持通信值。

而且，例如，当误差检测结果非常差时，即传播路径的情况如此差以致不能从多个天线传输不同的信息,使用与图 5 所示相同的频率从两个天线 106 和 116 选择性地传输相同的信息(传输 A = 传输 B),从而执行空间分集。或者，用图 6 所示不同的频率从两个天线 106 和 116 传输相同的信息(传输 A = 传输 B)，从而执行频率分集。在图 5 所示的示例中，避免了存在干扰波的 CH1、CH2、CH4，即分配到其它用户的频率(信道)，而且相同的传输信号(传输 A = 传输 B)是使用空闲相同信道(CH3)从系统 1 的天线 106 和系统 2 的天线 116 传输的空间分集。在图 6 所示的示例中，避免了存在干扰波的 CH1 和 CH4，即分配到其它用户的频率(信道)，并且传输信号是使用两个空闲信道 CH2 和 CH3 中的一个信道(CH2)从系统 1 的天线 106 传输的,并且与系统 1 相同的传输信号(传输信号 A = 传输信号 B)是使用与系统 1 不同的另一信道(CH3)来传输的。另外，这时，在前面的情况中，接收器 200 使用由发射器 100 使用的每个系统频率(图 5 示例中的 CH3 的频率)来执行接收操作。在后面的情况中，接收器 200 使用由发射器 100 使用的频率(图 6 示例中系统 1 使用 CH2 的频率和系统 2 使用 CH3 的频率)来执行接收操作。

根据该方法，当传播路径的情况非常差时，即，需要以传输速率的改善为代价来确保通信质量，执行空间分集或频率分集。为此，即使传播路径的情况如此差以致不能从多个天线传输不同的信息，也能够通过分集来维持通信质量。

因此，根据本实施例，当使用多个天线106和116来传输相同或不同的信息时，根据传播路径的情况来控制多个天线106和116的每个传输频率以及从多个天线106和116发射的信息数量，例如，根据传播路径的情况来自适应地选择空间复用、频率复用、空间分集和频率分集，并且这样能够进一步改善频谱效率和传输速率，同时保持通信质量。换句话说，能够同时获得通信质量的保持以及谱频率的进一步改善。

此外，根据本实施例，发射器100的自适应控制基于这种构思：即使存在空闲频率，首先使用相同的频率(为了其它用户以后能够容易地访问)，并且当通信质量不能得到保证时，使用不同的频率(然而，有必要检测不存在干扰波)。然而，自适应控制的控制概念并不限于此。

例如，能够采用这种构思：当没有干扰波存在时，不管传播路径的情况是否好或坏，用不同的频率来执行传输。具体地，例如，可以考虑下列使用。即，首先检测干扰波的存在与否，并且当干扰波不存在时，使用不同的频率，当操作期间检测到干扰波时，使用相同的频率。然后，当检测到干扰波在后来消失时，再次使用不同的频率。在这种情况中，由于不管传播路径的情况而使用没有干扰波的频率，将多个天线的每个传输频率设置为不同的频率，所以能够随便使用未分配的，即空闲的频率，并且能够减小来自其它用户的干扰的影响。

另外，本实施例解释了作为一个示例的OFDM无线通信装置。然而，本发明并不限于OFDM系统的应用。例如，本发明也能够应用于CDMA(码分多址)无线通信装置。

而且，本发明的无线发射装置能够安装在无线通信装置上，例如，移动通信系统中的无线基站装置和无线终端装置。

如上所解释的，根据本发明，能够进一步改善频谱效率和传输速率，同时保持通信质量。

本申请基于2001年10月31日提交的日本专利申请号2001-334392，在此全文引用，以供参考。

工业实用性

本发明可应用于无线装置，例如移动通信系统中的移动站装置和无线基站装置。

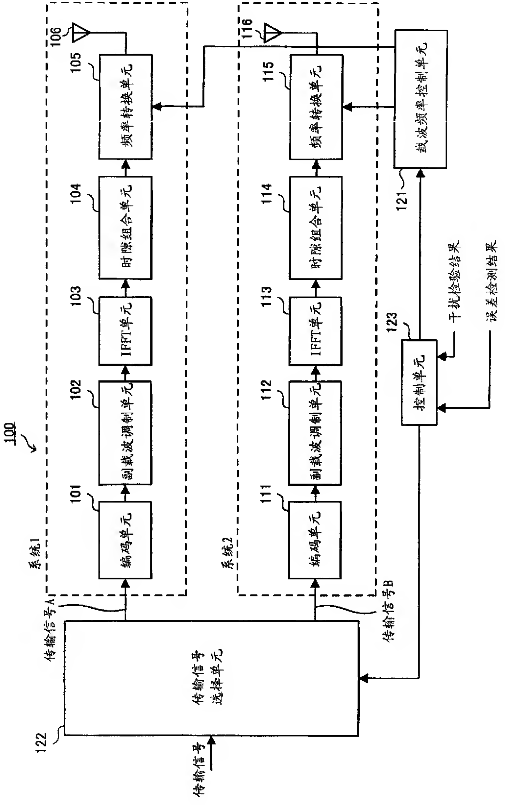

100
系统1
系统2
106
105
104
103
102
101
116
115
114
113
112
111
121
122
123
编码单元
副载波调制单元
IFFT单元
时隙组合单元
频率转换单元
载波频率控制单元
控制单元
干扰检验结果
误差检测结果
传输信号A
传输信号B
传输信号选择单元
传输信号

图 1

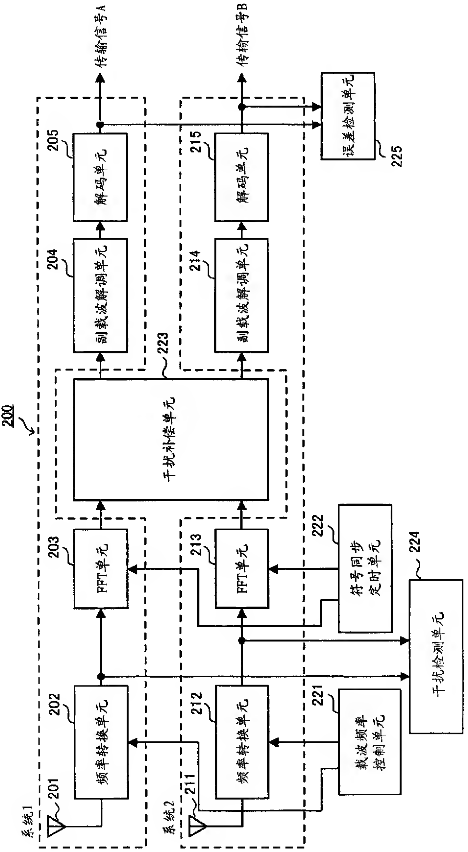

传输信号A
传输信号B
误差检测单元
225
205
解码单元
215
解码单元
204
副载波解调单元
214
副载波解调单元
223
干扰补偿单元
200
203
FFT单元
213
FFT单元
222
符号同步定时单元
224
干扰检测单元
202
频率转换单元
212
频率转换单元
221
载波频率控制单元
201
系统1
211
系统2

图 2

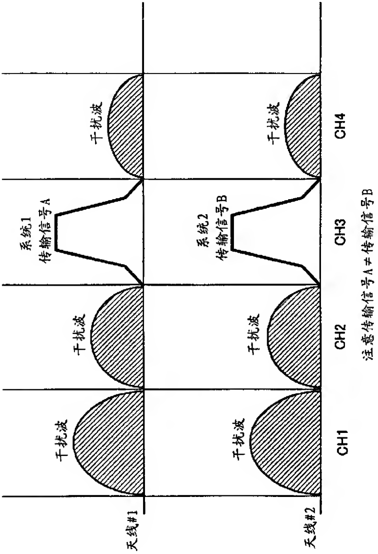

天线#1
天线#2
干扰波
干扰波
干扰波
干扰波
干扰波
干扰波
系统1
传输信号A
系统2
传输信号B
CH1
CH2
CH3
CH4
注意传输信号A≠传输信号B

图 3

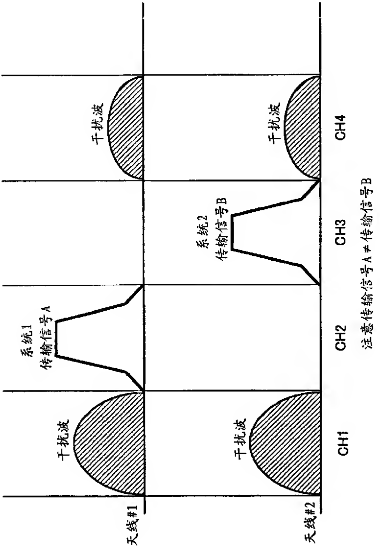

干扰波
系统1
传输信号A
干扰波
天线#1
干扰波
系统2
传输信号B
干扰波
天线#2
CH1
CH2
CH3
CH4
注意传输信号A≠传输信号B

图 4

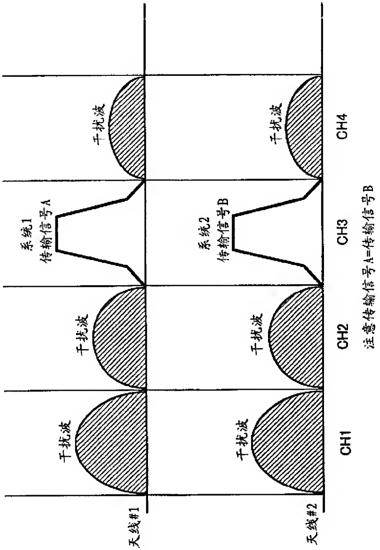
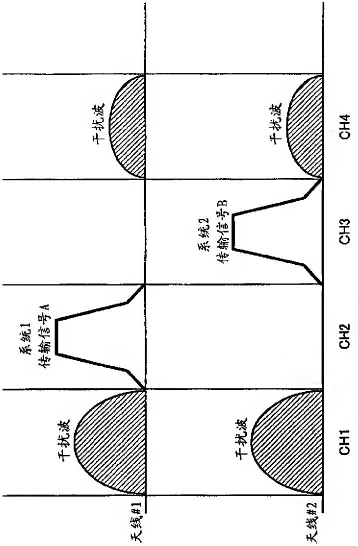

天线#1
天线#2
干扰波
干扰波
干扰波
干扰波
干扰波
干扰波
系统1
传输信号A
系统2
传输信号B
CH1
CH2
CH3
CH4
注意传输信号A=传输信号B

图 5



注意传输信号A=传输信号B

图 6

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(71) Applicant: **Advanced Digital Television Broadcasting Laboratory**
Tokyo (JP)

(72) Inventors:
- **Saito, Masafumi**
  Tokyo (JP)
- **Ikeda, Tetsuomi**
  Machida-shi, Tokyo (JP)

(74) Representative: **Lewald, Dietrich, Dipl.-Ing. et al**
Lewald . Grape . Schwarzensteiner
Patentanwälte
Rindermarkt 6
80331 München (DE)

(54) MCM system, with a plurality of data streams, each with its own transmission parameters

(57) Data sequences (D1 through DL) correspond to L different parameter sets (effective symbol length, guard interval length, the number of carrier waves) and transformed into parallel data by respective serial/parallel converters (111 through 11L), which are allocated to respective carrier waves for OFDM and subjected to inverse discrete Fourier transform by inverse discrete Fourier transformers (121 through 12L) to produce sampled values for the transmission waveform in the time domain. The sampled values are transformed into serial sequences of sampled values by parallel/serial converters (131 through 13L) and then into a single temporal sampling sequence by a temporal sampling sequence switching unit (14). A frame synchronizing symbol is added to the temporal sampling sequence and then transformed into an analog base band OFDM signal before it is converted up to a transmission signal. The frequency bandwidth of the OFDM signal is made smaller than a predetermined value defined by the bandwidth of the available transmission channel. As a result, an OFDM signal that can be received well regardless of the mode of reception can be transmitted.

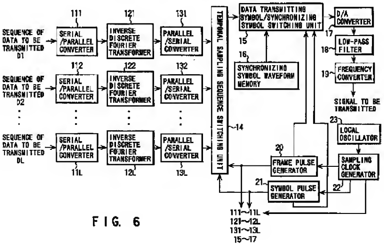


FIG. 6

EP 0 762 701 A2

Description

This invention generally relates to a transmission system for digital broadcasting and, more particularly, it relates to a data transmission system using orthogonal frequency division multiplexing (hereinafter referred to as OFDM) and digital modulation/demodulation. The present invention also relates to a transmitter and a receiver adapted to such a system.

The demand for digitized television broadcasting using ground waves has been increasing to improve the quality of television service. The OFDM transmission system appears to be particularly promising for ground wave digital signal transmission because it is robust against the multipath effect (or the ghost effect for television).

The OFDM transmission system is a variation of the multiple carrier modulation system, with which a transmission signal is produced by combining a large number (tens to thousands) of digitally modulated waves (carrier waves 1 through k) as typically illustrated in FIG. 1. Each of the carrier waves may be modulated in a mode selected from a number of different possible modes including QPSK, 16QAM and 64QAM.

The data transmission using the OFDM transmission system is realized by using transmission symbols as illustrated in FIG. 1, each of which constitutes a unit. Each transmission symbol comprises an effective symbol period and a guard interval. The effective symbol period is a signal period essential to data transmission. The guard interval is a redundant signal period designed to reduce the multipath effect by cyclically repeating the signal waveform of the effective symbol period.

If the gap between any two adjacent frequencies is made equal to the reciprocal number of the effective symbol period for OFDM transmission, the nil point of the frequency spectrum of each digitally modulated wave coincides with the center frequency of the adjacent modulated waves as shown in FIG. 2A so that no cross interference occurs between them. As seen from FIG. 2B, the spectrum of an OFDM signal shows a substantially rectangular profile as a whole. If the effective symbol period is ts and the number of carrier waves is K, then the frequency gap between any adjacent carrier waves is equal to 1/ts while the transmission bandwidth is equal to K/ts.

With the OFDM transmission system, a transmission frame is comprised of tens to hundreds of transmission symbols as shown in FIG. 1. FIG. 3 illustrates a typical OFDM transmission frame. The OFDM transmission frame contains frame synchronizing symbols, if necessary, along with data transmitting symbols. If necessary, it may additionally contain service identifying symbols.

FIG. 4 illustrates the concept of a transmitter A and a receiver B adapted to the OFDM transmission system.

The transmitter A divides a binary data to be transmitted into data blocks, each of which has a predetermined number of bits and is converted into a complex number prior to transmission. Serial/parallel converter A1 allocates different complex numbers Ci (i = 1 to N) to the carrier wave frequencies on a one by one basis and inverse discrete Fourier transform circuit A2 carries out an operation of inverse discrete Fourier transform to the time domain. As a result, sampled data are produced for a time base waveform so that a base band analog signal having a temporally continuous waveform is obtained from the sampled data and processed for frequency conversion by frequency converter A3 before it is transmitted.

The number of sampled values produced on a time base by inverse discrete Fourier transform is typically 2^n for each effective symbol period (n being a positive integer). Thus, if r_G is defined as r_G = (guard interval length)/(effective symbol length), then $2^n \cdot (1+r_G)$ samples are produced for each transmission symbol. The length of each transmission symbol is usually equal to the time interval of sampling points multiplied by an integer.

On the part of the receiver B, frequency converter B1 processes the received signal for frequency conversion to obtain a base band signal waveform, which is sampled at a sampling rate same as that of the transmitter. Discrete Fourier transform circuit B2 processes the sampled data to carry out an operation of discrete Fourier transform to the frequency domain and obtains by calculation the phase and the amplitude of each of the carrier wave frequency components to determine the value of each of the received data before they are converted into serial data by parallel/serial converter B3 and produced as data output.

While television signals are received either in the fixed mode or in the mobile mode (including the portable reception mode), a good reception is essential regardless of the mode of reception. With any known OFDM system, the effective symbol length, the guard interval length and the number of carrier waves of data transmitting symbols are determined mainly on the basis of either the fixed reception mode or the mobile reception mode. If the effective symbol length, the guard interval length and the number of carrier waves of data transmitting symbols are based mainly on, for example, the fixed reception mode, not the mobile reception mode, the influence of fading will be serious.

As pointed out above, with any known OFDM transmission system, the effective symbol length, the guard interval length and the number of carrier waves of data transmitting symbols are determined on the basis of the most popular reception mode because they cannot be selected so as to adapt themselves to more than one different modes.

It is, therefore, the object of the present invention to provide an OFDM transmission system that ensures a good signal reception regardless of the selected reception mode and a transmitter and a receiver adapted to such a system.

According to the invention, the above object is achieved by providing an OFDM transmission system for transmitting data by means of OFDM and digital modulation/demodulation, characterized in that, if the time interval of OFDM sam-

pling points is T, the effective symbol length NiT (Ni being a positive integer), the guard interval length MiT (Mi being zero or a positive integer) and the number of carrier waves Ki (Ki being a positive integer) of the i-th data transmission symbol in an OFDM transmission frame can take a plurality of respectively different values that can be arbitrarily selected, provided that Ki/NiT is kept smaller than a constant value W (W being a positive real number) determined by the bandwidth of the transmission channel.

In other words, with the OFDM transmission system according to the invention, two or more than two values are used for the effective symbol length and also for the guard interval length of a data transmission symbol and the symbol length is made equal to the sampling period, which is a basic unit for OFDM digital signal processing, multiplied by an integer. Additionally, the frequency bandwidth of OFDM transmission signal is made smaller than a constant value determined by the bandwidth of the transmission channel.

As a result, no cross interference appears if a plurality of data transmitting symbols having respective effective symbol lengths and guard interval lengths that are different from each other are multiplexed in a single transmission channel. Thus, the OFDM transmission system according to the invention can meet different conditions for data transmission in a single transmission channel without reducing the efficiency of the use of frequencies and entailing any cross interference among carrier waves.

This invention can be more fully understood from the following detailed description when taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a graph schematically showing signal transmission waveforms and a transmission symbol used for the OFDM transmission system;

FIGS. 2A and 2B are graphs schematically showing the frequency spectrum of the OFDM transmission system;

FIG. 3 is a graph schematically illustrating the configuration of a transmission frame of the OFDM transmission system;

FIG. 4 is a schematic block circuit diagram of a transmitter and a receiver adapted to a known OFDM transmission system;

FIG. 5 is a graph showing the frequency spectrum of an OFDM transmission system having a frequency block for the fixed reception mode and a frequency block for the mobile reception mode in a transmission channel;

FIG. 6 is a schematic block circuit diagram of an embodiment of a transmitter adapted to the OFDM transmission system of the invention;

FIG. 7 is a schematic block circuit diagram of an embodiment of a receiver adapted to the OFDM transmission system of the invention;

FIG. 8 is a graph schematically illustrating the configuration of a transmission frame of the OFDM transmission system according to the invention;

FIG. 9 is a graph schematically illustrating the relationship between the effective symbol length of an OFDM transmission symbol and the average transmission power level that can be used for another embodiment of the invention;

FIGS. 10A and 10B respectively show schematic block diagrams of an embodiment of a transmitter and that of a receiver according to the invention and designed to change the carrier wave frequencies at predetermined periods and a predetermined frequency gap;

FIGS. 11A and 11B show two alternative arrangements of carrier waves for shifting the frequency of each of the carrier waves within a base band in order to change the frequency at predetermined periods, of which FIG. 11A is designed for symbols for mobile reception whereas FIG. 11B is designed for symbols for fixed reception; and

FIG. 12 is a schematic view of a transmission frame comprising one or more data transmitting symbols for mobile and fixed receivers, where symbols for mobile reception are arranged at predetermined time periods.

The idea underlying the present invention will firstly be described. OFDM transmission symbols adapted to fixed reception and those adapted to mobile reception may be transmitted through a single transmission channel by dividing each OFDM signal into two frequency blocks on a frequency base, which frequency blocks are separated by a guard band in order to prevent interference from taking place among carrier waves, and selecting different values for the symbol length in these frequency blocks, which are respectively used for the fixed and mobile reception modes as shown in FIG. 5.

However, with the above method of dividing an OFDM signal into a plurality of blocks, the carrier waves which belong to different frequency blocks can not have an orthogonal relationship because the effective symbol length and the carrier wave frequency gap are differentiated from a frequency block to another, therefore, a guard band has to be provided between any adjacent frequency blocks at the cost of reducing the efficiency of the use of frequencies and the transmission bit rate of a transmission channel.

According to the invention, data transmitting symbols adapted to fixed reception and those adapted to mobile reception can be transmitted through a single transmission channel without providing one or more than one guard bands to prevent cross interference from occurring among carrier waves and hence without reducing the efficiency of

the use of frequencies.

With OFDM transmission systems, an FFT window having the same length as that of the effective symbol period is provided in each data transmitting symbol period and 2^n sampling points are subjected to an operation of discrete Fourier transform to the frequency domain in the demodulator.

The FFT window is arranged usually at the rear end of each transmission symbol. Note that no ghost can get into the FFT window in the demodulator from the adjacent symbol if the multipath delay time (or the ghost signal delay time for television) is shorter than the guard interval length. Therefore, the degradation due to the multipath phenomenon can be made far less serious than the degradation in a single carrier arrangement. Thus, with OFDM transmission systems, the influence of a ghost having a long delay time can be prevented by selecting a long guard interval to make the system substantially unaffected by the multipath phenomenon.

Now, an OFDM symbol length and a guard interval length adapted to fixed reception and those adapted to mobile reception will be discussed below.

Generally, the influence of multipath is one of the most important technological problems that have to be dealt with to achieve a good fixed reception for the OFDM system. As pointed out above, the use of a long guard interval is a useful technique for the prevention of the influence of ghost signals.

However, since the guard interval adversely affects the transmission capacity (bit rate) of a symbol in a manner as described above and the use of a long guard interval reduces the bit rate of a symbol having a given length, the effective symbol length has to be made proportional to the guard interval length and, therefore, a symbol having a long length has to be used to maintain a desired level of bit rate.

For the mobile reception mode, on the other hand, the characteristics of the transmission channel can change with time due to the fading phenomenon and, therefore, the use of a long OFDM symbol can result in an unnegligible change in the characteristics of the transmission channel within the time required for the transmission of a single symbol and hence a large bit error rate appears if the OFDM symbol length is too long. In other words, a long guard interval and hence a long symbol length operate disadvantageously for the fading phenomenon that can be observed in mobile reception. It may be safe to say that the portable reception mode is a combination of the fixed and mobile reception modes.

As discussed above, for the OFDM transmission system, the optimal values of the guard interval length, the effective symbol length and other transmission parameters may vary depending on the mode of reception. Therefore, a single set of values probably cannot optimize the reception in both the fixed and mobile reception modes. Thus, the OFDM transmission system according to the invention will be particularly useful when transmitting data through a single transmission channel for both the fixed and mobile reception modes, while using long symbols in the fixed reception mode.

Now, an embodiment of a transmitter and that of a receiver adapted to the OFDM transmission system according to the invention will be described in detail by referring to FIGS. 6 and 7.

FIG. 6 is a schematic block circuit diagram of an embodiment of a transmitter adapted to the OFDM transmission system of the invention. The transmitter comprises serial/parallel converters 111 through 11L, inverse discrete Fourier transformers 121 through 12L, parallel/serial converters 131 through 13L, a temporal sampling sequence switching unit 14, a data transmitting symbol/synchronizing symbol switching unit 15, a synchronizing symbol waveform memory 16, a D/A converter 17, a low-pass filter 18, a frequency converter 19, a frame pulse generator 20, a symbol pulse generator 21, a sampling clock generator 22 and a local oscillator 23.

A total of L sequential data D1 through DL to be transmitted are applied respectively to the L serial/parallel converters 111 through 11L. A set of L parameters (effective symbol length, guard interval length, number of carrier waves) are provided to correspond to the L sequential data D1 through DL to be transmitted.

Said serial/parallel converters 111 through 11L convert respective serial data into parallel data, which are allocated respectively to the carrier waves of the OFDM transmission system. The inverse discrete Fourier transformers 121 through 12L determines the phases and the amplitudes of the respective carrier waves on the basis of the data allocated for transmission. The phase and the amplitude of each of the carrier waves are treated as a complex number in the frequency domain and subjected to an operation of inverse discrete Fourier transform and the sampled values of the transmission waveform obtained in the time domain are produced as outputs. Then, the parallel/serial converters 131 through 13L convert the temporally sampled values produced in parallel into a sequence of serially sampled values for each symbol.

On the other hand, the sampling clock generator 22 generates a sampling clock on the basis of the original oscillation frequency signal produced by the local oscillator 23. The frame pulse generator 20 and the symbol pulse generator 21 respectively generate a frame pulse and a symbol pulse from the sampling clock. The sampling clock, the frame pulse and the symbol pulse are fed to the components of the transmitter for timing purposes.

The temporal sampling sequence switching unit 14 selectively switches the L sequences of temporal samples to transform them into a single sequence of temporal samples by using the frame pulse and the symbol pulse. The synchronizing symbol waveform memory 16 produces the sampled values of the frame synchronizing symbol waveform. The data transmitting symbol/synchronizing symbol switching unit 15 switches the sequence of temporally sampled values of the data transmitting symbol produced by the temporal sampling sequence switching unit 14 and the sequence

of sampled values of the waveform of the frame synchronizing symbol produced by the synchronizing symbol waveform memory 16 to transform them into a sequence of temporally sampled values of the base band OFDM signal.

The D/A converter 17 converts the sequence of temporally sampled values into an analog signal and the low-pass filter 18 eliminates the high frequency components of the analog signal to produce an analog base band OFDM signal. The frequency converter 19 converts the frequency of the base band OFDM signal up to an intermediate frequency or a radio frequency and produces a signal to be transmitted.

FIG. 7 is a schematic block circuit diagram of an embodiment of a receiver adapted to the OFDM transmission system of the invention. It comprises a band-pass filter 31, a frequency converter 32, a synchronizing symbol waveform memory 33, a synchronizing symbol position detector 34, an oscillation frequency control signal generator 35, a local oscillator 36, a sampling clock generator 37, a frame pulse generator 38, a symbol pulse generator 39, an A/D converter 40, serial/parallel converters 411 through 41L, discrete Fourier transformers 421 through 42L and demodulation-parallel/serial converters 431 through 43L.

In the receiver having the configuration described above, the band-pass filter 31 eliminates the out-of-band components and the frequency converter 32 converts the intermediate frequency or the radio frequency of the OFDM signal down to a base band. The A/D converter 40 transforms the base band OFDM signal into a sequence of sampled digital values, which are respectively fed to the serial/parallel converter 411 through 41L and also to the synchronizing symbol position detector 34.

The synchronizing symbol position detector 34 detects the position of the front end of the frame by calculating the correlated values of the sequence of sampled values of the base band OFDM signal and the sequence of sampled values of the synchronizing symbol waveform stored in the synchronizing symbol waveform memory 33. It also determines the position for switching the transmitting symbols and the position of the FFT window.

The oscillation frequency control signal generator 35 generates a signal for controlling the oscillation frequency of the local oscillator 36 on the basis of the frame period detected by the synchronizing symbol position detector 34. A method of controlling the local oscillation frequency by means of a frame period is described in Japanese Patent Application No. 6-138386 "Clock frequency automatic control method and transmitter and receiver using the same".

The sampling clock generator 37 generates a sampling clock on the basis of the original oscillation frequency signal produced by the local oscillator 36. The frame pulse generator 38 and the symbol pulse generator 39 respectively generate a frame pulse and a symbol pulse on the basis of the data on the position of the front end of the frame produced by the synchronizing symbol position detector 34 and the sampling clock. The sampling clock, the frame pulse and the symbol pulse are respectively fed to the related components of the receiver and used to generate various timing signals.

The serial/parallel converter 411 through 41L transform the sequence of sampled base band values into parallel data, which are fed then to the discrete Fourier transformers 421 through 42L. The discrete Fourier transformers 421 through 42L transform the sampled values in the time domain into spectra for the respective carrier wave frequencies. The demodulation-parallel/serial converters 431 through 43L estimate the phases and the amplitudes of the carrier waves from the respective frequency component, determines the values of the received data on the basis of the phases and the amplitudes and transform them into sequences of serial received data D1 through DL, which are then produced by the converters as respective outputs. The L sequences of received data D1 through DL corresponds to the L parameter sets.

In the transmission system having the configuration described above, the inverse discrete Fourier transformer 12i (i being an integer between 1 and L) and the discrete Fourier transformer 42i (i being an integer between 1 and L) arbitrarily select Ni, Mi and Ki provided that Ki/NiT is kept smaller than a constant value W (W being a positive real number) determined by the bandwidth of the transmission channel, where T is the time interval of sampling clocks, NiT is the effective symbol length (Ni being a positive integer), MiT is the guard interval length (Mi being zero or a positive integer) and Ki is the number of carrier waves (Ki being a positive integer).

The temporal sampling sequence switching unit 14 switches the data transmitting symbols in such an order that the data transmitting symbols having an identical effective symbol length and a guard interval length are continuously arranged on the time base and the number of switching points where two adjacent data transmitting symbols having at least mutually different effective symbol lengths or mutually different guard interval lengths are located is minimized.

While there may be a number of different orders according to which symbols corresponding to data sequences D1 through DL are transmitted, data transmitting symbols corresponding to a sequence of data (a set of parameters) are to be most basically transmitted in an continuous order on the time base. Then, the number of switching points where two adjacent data transmitting symbols having respective sets of parameters that are different from each other are located is minimized. FIG. 8 shows a typical arrangement of data transmitting symbols that meets the above requirements.

Assuming L = 2 and that sequence D1 of transmission data is for the fixed reception mode and sequence D2 of transmission data is for the mobile reception mode, a good data reception can be realized in either mode by selecting respective sets of parameters for fixed reception and mobile reception for the inverse discrete Fourier transformers 121 and 122.

Thus, with the OFDM transmission system according to the invention, any cross interference can be prevented from appearing between two adjacent carrier waves without using a guard band so that various different requirements of transmission can be met within a single transmission channel without reducing the efficiency of the use of frequencies. Specifically, OFDM data transmitting symbols good for fixed reception and those adapted to mobile reception can be transmitted through a single transmission channel without reducing the efficiency of the use of frequencies.

While L inverse discrete Fourier transformers 121 through 12L are used for L different parameter sets in the arrangement of FIG. 6, a single inverse discrete Fourier transformer may cover L different symbol lengths if it is adapted to the use of a plurality of FFT points.

While the technique of modulation to be used for the OFDM carrier waves may be selected depending on the phase and the amplitude assigned to each carrier wave in the form of a complex number in the frequency domain, different techniques of modulation may be respectively used for sequences D1 through DL of transmission data, typically including techniques such as DQPSK, 16QAM and 64QAM.

Similarly, while L discrete Fourier transformers 421 through 42L are used for L different parameter sets in the arrangement of FIG. 7, a single discrete Fourier transformer may cover L different symbol lengths if it is adapted to the use of a plurality of FFT points.

Of the L data sequences D1 through DL, the sequence D1, for example, and the corresponding transmission symbols may be used to transmit data on the effective symbol lengths, the guard interval lengths, the number of carrier waves and the modulation techniques selected for the carrier waves for the remaining data sequences D2 through DL from the transmitter to the receiver.

Generally speaking, if the effective symbol length NaT (Na being a positive integer), the guard interval length MaT (Ma being zero or a positive integer) and the number of carrier waves Ka (Ka being a positive integer) of a specific data transmitting symbol in an OFDM transmission frame are known by the receiver along with the modulation techniques selected for the carrier waves of the specific symbol, the parameter sets for the data transmitting symbols can be modified by transmitting at least part of the data on the effective symbol lengths, the guard interval lengths, the number of carrier waves and the modulation techniques selected for the respective carrier waves of all the data transmitting symbols other than said specific data transmitting symbol in the frame from the transmitter to the receiver by means of said specific symbol.

If the average transmission power required for the i-th data transmitting symbol can be Pi in the OFDM frame of the above embodiment, Pi can be determined as a function of Ni that defines the effective symbol length in the frame so that Pi and Ni provide a one-to-one correspondence. If, additionally, there are L different possible values of Ni, there will also be L different possible values of Pi so that the average transmission power Pi may vary depending on the effective symbol length NiT of each data transmitting symbol.

With such an arrangement, different service areas may be provided for fixed reception and for mobile reception by selecting different values of the average transmission powers for fixed reception and for mobile reception.

If, in the above embodiment, the value of Ni is selected from A1, A2, ..., AL and Amax is the largest value of A1, A2, ..., AL, all the numbers Al, A2, ..., AL may be so selected as to be divisors of Amax that can exactly divide the latter. In other words, if the effective symbol length NiT is selected from A1T, A2T, ..., ALT and AmaxT is the largest value of AlT, A2T, ..., ALT, they are divisors of AmaxT that can exactly divide the latter.

Then, all the data transmitting symbols can commonly share part of the carrier waves. Therefore, data on carrier phase necessary for coherent demodulation or control data can be transmitted by means of such commonly shared carrier waves.

On the other hand, if Mi that defines the guard interval length can take only a single value, that is, if there are a plurality of values that the effective symbol length NiT can take and the guard interval length MiT can take only a single value, then the layer for fixed reception and that for mobile reception in each transmission frame will perform exactly in a same manner against inter-symbol interference due to multipath.

Finally, the frequencies of the carrier waves for the data transmitting symbols in an OFDM transmission frame may be shifted with a predetermined period and a predetermined frequency interval. More specifically, the frequencies of the carrier waves of data transmission symbols having a relatively few number of carrier waves (or symbols for mobile reception) may be shifted by the frequency interval of the carrier waves of other data transmission symbols having a relatively large number of carrier waves (or symbols for fixed reception) multiplied by an integer.

With such an arrangement, data on carrier phase necessary for coherent demodulation of symbols for fixed reception or data for equalization can be transmitted by means of the carrier waves of symbols for mobile reception.

More specifically, the frequencies may be shifted in a radio frequency band or in a base band. FIGS. 10A and 10B are circuit configurations adapted to the former, whereas FIGS. 11A and 11B illustrates possible arrangements of carrier waves adapted to the latter. The components common to those of FIGS. 6 and 7 are respectively denoted by the same reference symbols.

(1) Frequency Shift in a Radio Frequency Band

FIG. 10A shows a circuit configuration of a transmitter designed for a frequency shift in a radio frequency band. Variable frequency local oscillator 24 shifts the oscillation frequency according to the transmission symbol by means of the frame pulse and the symbol pulse fed respectively from the frame pulse generator 20 and the symbol pulse generator 21 shown in FIG. 6. The frequency converter 19 shown in FIG. 6 can be driven by the shifted oscillation frequency to generate, for each data transmitting symbol, signals having frequencies shifted.

FIG. 10B shows a circuit configuration of a receiver designed for a frequency shift in a radio frequency band. Variable frequency local oscillator 44 shifts the oscillation frequency according to the transmission symbol by means of the frame pulse and the symbol pulse fed respectively from the frame pulse generator 38 and the symbol pulse generator 39 shown in FIG. 7. The frequency converter 32 shown in FIG. 7 can be driven to convert the OFDM signal having an intermediate or radio frequency down to a base band.

(2) Frequency Shift in a Base Band

FIG. 11A shows an arrangement of carrier wave frequencies of symbols for mobile reception. FIG. 11B shows an arrangement of carrier wave frequencies of symbols for fixed reception. In the example shown in FIGS. 11A and 11B, m = 10 and n = 40, where m is the number of carrier wave frequencies provided for the mobile-reception symbols, and n is the number of carrier wave frequencies provided for the fixed-reception symbols.

Numerals 1 to n are assigned to the carrier-wave frequencies at the input of the inverse discrete Fourier transformer provided in the transmitter. The numerals will be referred to as "frequency slot numbers." Further, numerals 1, 2, 3, ... are assigned to the symbols for data transmission. In the symbol 1 for mobile reception, data is set to the inverse discrete Fourier transformer, in every (n/m)th slot, starting with the slot 1; in the symbol 2, data is set in every (n/m)th slot, starting with the slot 2, and so forth. The inverse discrete Fourier transformer which has n points converts the data to the time domain. A signal having frequencies shifted along the time axis as shown in FIG. 11A is thereby generated.

In the symbols for fixed reception, data are set at all n points of the inverse discrete Fourier transformer, as is illustrated in FIG. 11B. The transformer performs inverse discrete Fourier transform on the data.

On the demodulation side, too, a discrete Fourier transformer having n points is used. After the discrete Fourier transform has been performed, a symbol for mobile reception is demodulated by selecting only the frequency slots which are used in the symbol.

In the embodiment described above, one or more data transmitting symbols for mobile reception which have relatively short effective length and guard interval length may be transmitted at regular time intervals within a frame, as is illustrated in FIG. 12. The embodiment can thereby realize a time interleaving effect against fading in mobile reception. This reduces burst errors and also the memory capacity required for interleaving, than in the case where symbols for mobile reception are transmitted continuously.

The above embodiment may be used for ATM telecommunications where the amount of data to be transmitted can vary as a function of time and also for transmission of data encoded in the form of variable length codes, by modifying the transmission parameters including the effective symbol length, the guard interval length, the number of carrier waves and the modulation techniques for each carrier wave by means of a specific data transmitting symbol to modify the amount of data to be transmitted on a frame basis.

The present invention is not limited to the above embodiment, which may be subjected to various changes and modifications.

Thus, the invention provides an OFDM transmission system that ensures a good reception regardless of the mode of reception and a transmitter and a receiver adapted to such a system.

Claims

1. An orthogonal frequency division multiplexing (hereinafter referred to as OFDM) transmission system for transmitting data by means of OFDM and digital modulation/demodulation, characterized in that, if the time interval of OFDM sampling points is denoted as T, the effective symbol length NiT (Ni being a positive integer), the guard interval length MiT (Mi being zero or a positive integer) and the number of carrier waves Ki (Ki being a positive integer) of the i-th data transmission symbol in an OFDM transmission frame, Ni, Mi and Ki can take a plurality of respective different values that can be arbitrarily selected, provided that Ki/NiT is kept smaller than a constant value W (W being a positive real number) determined by the bandwidth of the transmission channel.

2. An orthogonal frequency division multiplexing transmission system according to claim 1, characterized in that, if the effective symbol length NaT (Na being a positive integer), the guard interval length MaT (Ma being zero or a positive integer) and the number of carrier waves Ka (Ka being a positive integer) of a specific data transmitting symbol in an OFDM transmission frame are known by the receiver along with the modulation techniques selected for the

carrier waves of the specific symbol, at least part of the data on the effective symbol lengths, the guard interval lengths, the number of carrier waves and the modulation techniques selected for the respective carrier waves of all the data transmitting symbols other than said specific data transmitting symbol in the frame are transmitted from the transmitter to the receiver by means of said specific symbol.

3. An orthogonal frequency division multiplexing transmission system according to claim 1, characterized in that data transmitting symbols are transmitted in such an order that the data transmitting symbols having an identical effective symbol length and a guard interval length are continuously arranged on the time base and the number of switching points where two adjacent data transmitting symbols having at least mutually different effective symbol lengths or mutually different guard interval lengths are located is minimized.

4. An orthogonal frequency division multiplexing transmission system according to claim 1, characterized in that said OFDM transmission frame comprises data transmitting symbols having a relatively long effective symbol length and a relatively long guard interval length for fixed reception and those having a relatively short effective symbol length and a relatively short guard interval length for mobile reception.

5. An orthogonal frequency division multiplexing transmission system according to claim 4, characterized in that it is used for digital television broadcasting.

6. An orthogonal frequency division multiplexing transmission system according to claim 1, characterized in that, if the average transmission power required for the i-th data transmitting symbol is Pi in the OFDM frame of the above embodiment, Pi is determined as a function of Ni that defines the effective symbol length in the frame so that Pi and Ni provide a one-to-one correspondence and that, if there are L different values Ni can take, there are also provided L diffarant values Pi can take.

7. An orthogonal frequency division multiplexing transmission system according to claim 1, charactarized in that, if the value of Ni is selected from A1, A2, ..., AL and Amax is the largest value of A1, A2, ..., AL, all the numbers Al, A2, ..., AL are so selected as to be divisors of Amax that can exactly divide the latter.

8. An orthogonal frequency division multiplexing transmission system according to claim 1, characterized in that Mi can take a single value.

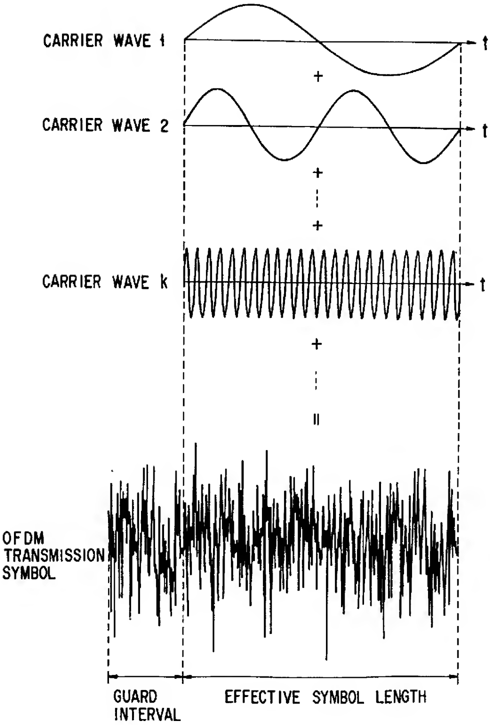
9. An orthogonal frequancy division multiplexing transmission system according to claim 1, charactarized in that the frequencies of the carrier waves for the data transmitting symbols in said OFDM transmission frame are shifted with a predetermined period and a predetermined frequency interval.

10. An orthogonal frequency division multiplexing transmission system according to claim 4, characterized in that at least one data transmitting symbols having a relatively short effective symbol length and a relatively short guard interval length for mobile reception are transmitted at a predetermined time intarval within a frame.

11. An orthogonal frequency division multiplexing transmission system according to claim 2, characterized in that at least one of the effective symbol length, the guard interval length, the number of carrier waves and the modulation techniques is modified for each OFDM transmission frame by means of a specific data transmitting symbol on an OFDM transmission frame basis.

12. A transmitter adapted to an orthogonal frequency division multiplexing transmission system according to claim 1, characterized in that, if L FFT points are used for the modulation of data transmitting symbols in inverse discrete Fourier transform, a total of L inverse discrete Fourier transformers (121, 122, ..., 12L) are provided for each number of FFT points.

13. A receiver adapted to an orthogonal frequency division multiplexing transmission system according to claim 1, characterized in that, if L FFT points are used for the demodulation of data transmitting symbols in discrete Fourier transform, a total of L discrete Fourier transformers (421, 422, ..., 42L) are provided for each number of FFT points.


CARRIER WAVE 1
t
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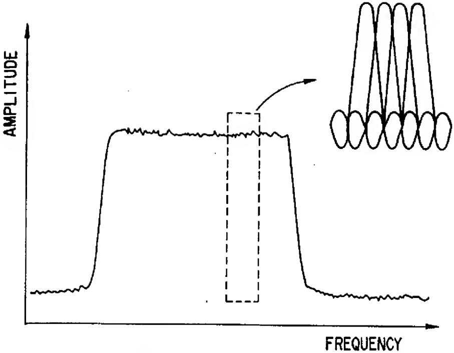
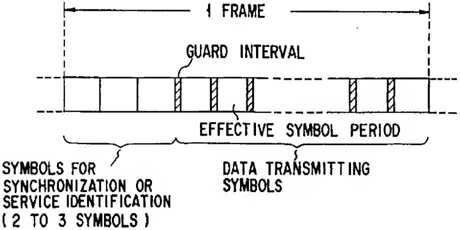
OFDM TRANSMISSION SYMBOL
GUARD INTERVAL
EFFECTIVE SYMBOL LENGTH

F I G. 1

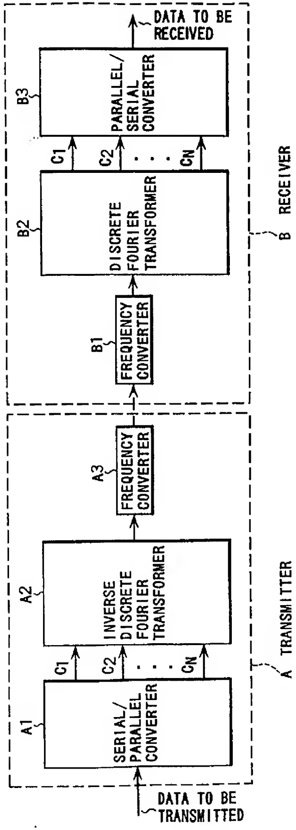
F I G. 2A



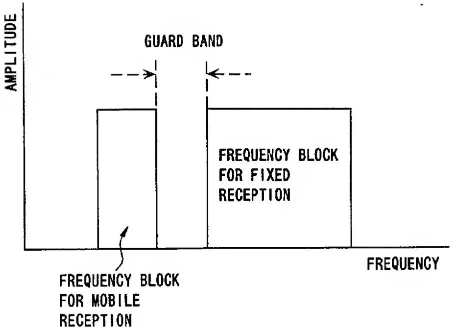
F I G. 2B



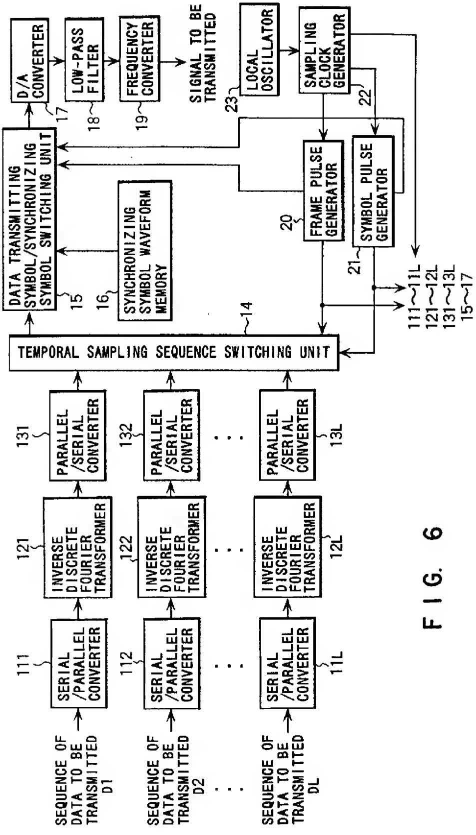
F I G. 3


DATA TO BE TRANSMITTED
A1
SERIAL/ PARALLEL CONVERTER
C1
C2
CN
A2
INVERSE DISCRETE FOURIER TRANSFORMER
A3
FREQUENCY CONVERTER
A TRANSMITTER
B1
FREQUENCY CONVERTER
B2
DISCRETE FOURIER TRANSFORMER
C1
C2
CN
B3
PARALLEL/ SERIAL CONVERTER
DATA TO BE RECEIVED
B RECEIVER

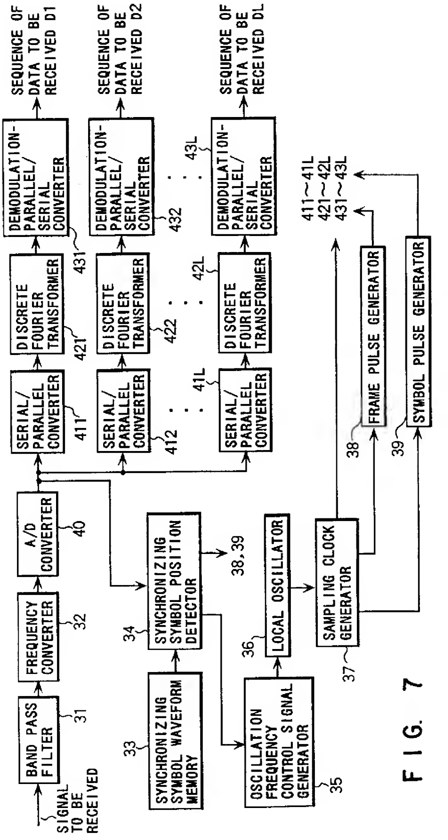
F I G. 4


AMPLITUDE
GUARD BAND
FREQUENCY BLOCK
FOR FIXED
RECEPTION
FREQUENCY
FREQUENCY BLOCK
FOR MOBILE
RECEPTION

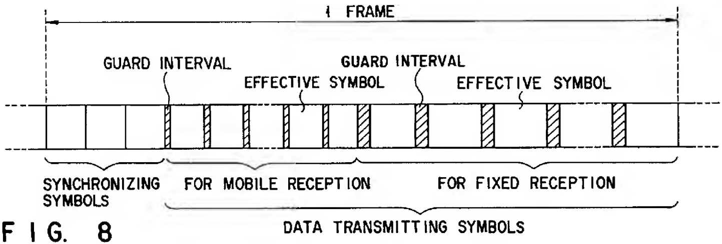
F I G. 5


D/A CONVERTER
17
LOW-PASS FILTER
18
FREQUENCY CONVERTER
19
SIGNAL TO BE TRANSMITTED
LOCAL OSCILLATOR
23
SAMPLING CLOCK GENERATOR
22
DATA TRANSMITTING SYMBOL/SYNCHRONIZING SYMBOL SWITCHING UNIT
15
SYNCHRONIZING SYMBOL WAVEFORM MEMORY
16
FRAME PULSE GENERATOR
20
SYMBOL PULSE GENERATOR
21
111~11L
121~12L
131~13L
15~17
14
TEMPORAL SAMPLING SEQUENCE SWITCHING UNIT
131
PARALLEL /SERIAL CONVERTER
132
PARALLEL /SERIAL CONVERTER
13L
PARALLEL /SERIAL CONVERTER
121
INVERSE DISCRETE FOURIER TRANSFORMER
122
INVERSE DISCRETE FOURIER TRANSFORMER
12L
INVERSE DISCRETE FOURIER TRANSFORMER
111
SERIAL /PARALLEL CONVERTER
112
SERIAL /PARALLEL CONVERTER
11L
SERIAL /PARALLEL CONVERTER
SEQUENCE OF DATA TO BE TRANSMITTED D1
SEQUENCE OF DATA TO BE TRANSMITTED D2
SEQUENCE OF DATA TO BE TRANSMITTED DL

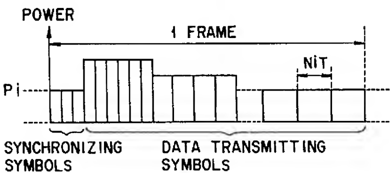
F I G. 6


SIGNAL TO BE RECEIVED
BAND PASS FILTER
31
FREQUENCY CONVERTER
32
A/D CONVERTER
40
SERIAL/ PARALLEL CONVERTER
411
DISCRETE FOURIER TRANSFORMER
421
DEMODULATION- PARALLEL/ SERIAL CONVERTER
431
SEQUENCE OF DATA TO BE RECEIVED D1
SERIAL/ PARALLEL CONVERTER
412
DISCRETE FOURIER TRANSFORMER
422
DEMODULATION- PARALLEL/ SERIAL CONVERTER
432
SEQUENCE OF DATA TO BE RECEIVED D2
SERIAL/ PARALLEL CONVERTER
41L
DISCRETE FOURIER TRANSFORMER
42L
DEMODULATION- PARALLEL/ SERIAL CONVERTER
43L
SEQUENCE OF DATA TO BE RECEIVED DL
SYNCHRONIZING SYMBOL WAVEFORM MEMORY
33
SYNCHRONIZING SYMBOL POSITION DETECTOR
34
38, 39
OSCILLATION FREQUENCY CONTROL SIGNAL GENERATOR
35
LOCAL OSCILLATOR
36
SAMPLING CLOCK GENERATOR
37
FRAME PULSE GENERATOR
38
SYMBOL PULSE GENERATOR
39
411~41L
421~42L
431~43L

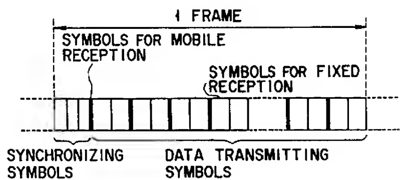
F I G. 7



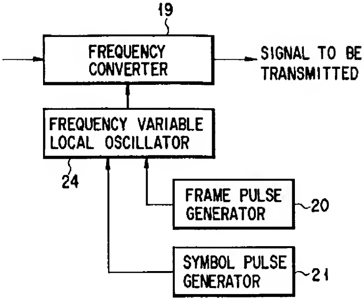
F I G. 8



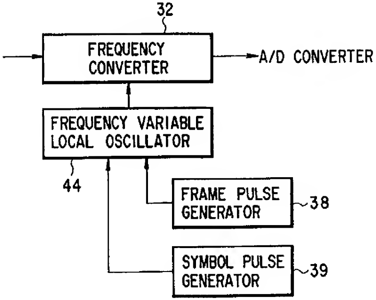
F I G. 9



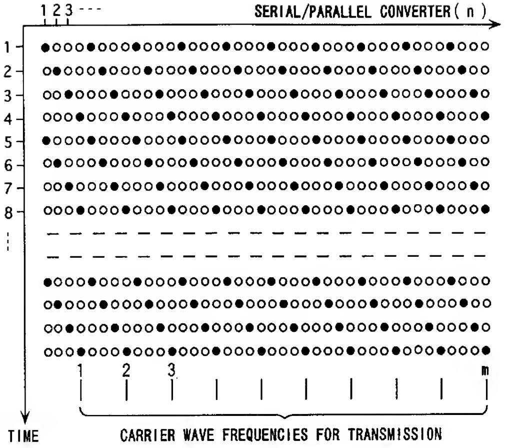
F I G. 12



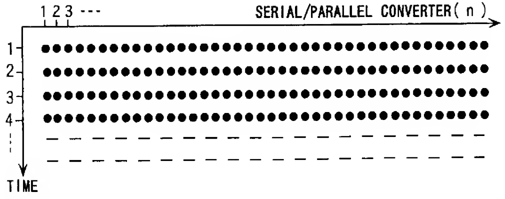
F I G. 10A



F I G. 10B



F I G. 11A



F I G. 11B

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(71) Applicant:
LUCENT TECHNOLOGIES INC.
Murray Hill, New Jersey 07974-0636 (US)

(72) Inventor: Van Nee, C.J. Richard
3454 CG de Meern (NL)

(74) Representative:
Watts, Christopher Malcolm Kelway, Dr.
Lucent Technologies (UK) Ltd,
5 Mornington Road
Woodford Green Essex, IG8 0TU (GB)

(54) Multicarrier modulation system, with variable symbol rates

(57) An OFDM system uses a normal mode which has a symbol length T, a guard time T_G and a set of N sub-carriers, which are orthogonal over the time T, and one or more fallback modes which have symbol lengths KT and guard times KT_G where K is an integer greater than unity. The same set of N sub-carriers is used for the fallback modes as for the normal mode. Since the same set of sub-carriers is used, the overall bandwidth is substantially constant, so alias filtering does not need to be adaptive. The Fourier transform operations are the same as for the normal mode. Thus fallback modes are provided with little hardware cost. In the fallback modes the increased guard time provides better delay spread tolerance and the increased symbol length provides improved signal to noise performance, and thus increased range, at the cost of reduced data rate.

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Description

Technical Field

[0001] This invention relates to communication systems and, more particularly, OFDM (Orthogonal Frequency Division Multiplexing) modulation schemes.

Background of the Invention

[0002] OFDM is a block-oriented modulation scheme that maps N data symbols into N orthogonal sub-carriers separated by a frequency interval of 1/T, where T is the symbol duration, i.e. the time period over which the sub-carriers are orthogonal. As such, multi-carrier transmission systems use OFDM modulation to send data bits in parallel over multiple sub-carriers (also called tones or bins). An important advantage of multi-carrier transmission is that inter-symbol interference due to signal dispersion (or delay spread) in the transmission channel can be reduced or even eliminated by inserting a guard time interval T_G between the transmission of subsequent symbols, thus avoiding an equaliser as required in single carrier systems. This gives OFDM an important advantage over single carrier modulation schemes. The guard time allows delayed copies of each symbol, arriving at the receiver after the intended signal, to die out before the succeeding symbol is received. OFDM's attractiveness stems from its ability to overcome the adverse effects of multi-channel transmission without the need for equalisation.

[0003] The transformations between blocks of symbols and base-band carrier signal are normally carried out using fast Fourier transform (FFT) techniques. A discussion of OFDM is given by Alard and Lasalle, EBU Technical Review, no. 224, August 1987, pages 168-190.

[0004] A need exists for a flexible OFDM system which provides the advantages of OFDM to a variety of communication environments.

[0005] In a previous patent application (US, serial No. 08/834684, herein referred to as VN) I disclosed several techniques to scale data rates using OFDM. Scaling methods involve changing the clock rate, FFT size, coding rate, constellation size and guard time.

[0006] The present invention is intended to provide fallback rates with a minimum change in hardware.

Summary of the Invention

[0007] The invention is as set out in the independent claims, preferred forms being set out in the dependent claims.

[0008] In a preferred embodiment of the present invention, a first signalling mode (the 'normal' mode) uses a symbol length T, a guard time T_G and a set of N sub-carriers and a second mode (the 'fallback' mode) uses a symbol length KT, a guard time KT_G and the same set of N sub-carriers, where K is an integer greater than unity.

[0009] The technique can increase the range and delay spread tolerance without substantially changing the bandwidth and without changing the FFT size, at the cost of a decreased bit rate. Further, the fallback rates can also be used to provide a multiple access capability, so using fallback rates does not necessarily result in a bad spectral efficiency.

Brief Description of the Drawings

[0010]

Figures 1 and 2 illustrate the transmission of an OFDM symbol in K = 1 mode and K = 2 mode according to the invention,

Figure 3 shows, in block schematic form, a transmitter embodying the invention; and

Figure 4 shows, in block schematic form, a receiver embodying the invention.

[0011] Figure 1 shows an OFDM symbol transmitted with a symbol duration T and a guard time T_G. The object of the guard time T_G is to accommodate any interference between consecutive symbols due to dispersion or multi-path interference (collectively referred to as 'delay spread'), and to leave a time T over which the symbol can be received free from such interference. Under some conditions, or in some applications, it may happen that the guard time T_G is insufficient to accommodate this delay spread (as in Figure 1). It may also happen that a greater range will be required, i.e. a higher signal-to-noise ratio in the recovered signal. Simply increasing the guard time T_G would accommodate a larger delay spread, though it would not affect the range. Decreasing the clock rate seems a simple way of increasing the guard time T_G and the symbol duration T, but it would also decrease the frequency spacing 1/T between the sub-carriers. This would proportionately decrease the overall bandwidth of the channel, which would mean that the filters that are required to remove aliases would have to be adaptable, thus increasing the hardware requirement.

[0012] Figure 2 shows a symbol which has been transmitted with twice the symbol duration 2T and with twice the guard time $2T_G$. The guard time is now doubled, and can accommodate the illustrated intersymbol interference. Also, since the symbol duration is doubled, the signal-to-noise performance, and hence the range, is improved. It is important to note that the frequencies of the sub-carriers are not also halved as would be the case with a simple halving of the clock rate. The same set of sub-carriers is used, still separated by 1/T, not 1/2T. Therefore, the overall bandwidth of the channel, which is mainly determined by the spread of sub-carrier frequencies, and only to a much lesser extent by the widths of the individual sub-carriers, is substantially

unchanged.

[0013] Since for any OFDM symbol, the signal repeats itself after T seconds, where T is the FFT interval, it is possible to do 2 FFTs on two different parts of the received symbol, each with a length of T seconds. Since both FFT outputs carry the same data, but different noise, they can be averaged to get a 3 dB increase in signal-to-noise ratio. The FFT is a linear operation, so it is also possible to first average two T seconds intervals and use this averaged signal as input to a single FFT. This scheme can easily be extended to other data rates; in general, any rate which is a factor K less than the highest bit rate can be produced by extending the symbol duration by a factor of K. By taking K FFTs per symbol, a processing gain of K is achieved which increases the range. At the same time, the delay spread tolerance is increased by a factor of K. The only extra hardware required is for averaging K consecutive signal intervals of T seconds. In fact, the amount of processing in terms of operations per second is decreased for fallback rates, because the averaging takes far less processing than the FFT. Consider, for instance, the case of an OFDM modem with a 64 point FFT and a symbol duration of 2µs. A 64 point FFT involves about 192 complex multiplications and additions, so the procesing load is 96 Mops, where an operation is defined as one complex multiply plus one addition. If the symbol duration is doubled to create a fallback rate, then in 4µs, 64 additions have to be performed plus one 64 point FFT. Thus, the processing load becomes (192+64)/4µs = 64 Mops. In fact, this figure is pessimistic, because the extra additions have been given the same weight as multiplications, while they are significantly less complex when implemented in hardware. The additions are the only part of the receiver that has to run at the full clock rate; the FFT and everything following the FFT (channel estimation, decoding) can run at a rate that is K times lower than the original rate, which helps to reduce the power consumption.

[0014] Figure 3 shows an OFDM transmitter which receives a stream of data bits. A coding circuit 1 receives the data stream and partitions it into successive groups or blocks of bits. The coding circuit 1 introduces redundancy for forward error correction coding.

[0015] The blocks of coded data bits are input into a N-points complex IFFT (Inverse Fast Fourier Transform) circuit 2 where N is the number of the OFDM sub-carriers. In this particular embodiment, using quaternary phase-shift keying (QPSK), the IFFT is performed on blocks of 2N coded data bits received from the coding circuit 1. In practice, the transmitter has to use oversampling to produce an output spectrum without aliasing which introduces unwanted frequency distortion due to (intended or unintentional) low pass filtering in subsequent stages of the transmitter or in the transmission channel. Thus, instead of a N-points IFFT an M-points IFFT is actually done where M>N to perform the oversampling. These 2N bits are converted into N complex numbers, and the remaining M-N input values are set to zero.

[0016] To decrease the sensitivity to inter-symbol interference, the cyclic prefixer and windowing block 3 copies the last part of the OFDM symbol and augments the OFDM symbol by prefixing it with the copied portion of the OFDM symbol. This is called cyclic prefixing. Control circuitry 4 controls the cyclic prefixer and windowing block 3 to switch the guard time and the symbol duration as required, or as appropriate, between their normal values T_G and T respectively and their fallback values KT_G and KT respectively. To provide the fallback values the cyclic prefixer has to augment the OFDM symbol with K-1 copies of itself, in addition to the prefix, which is preferably K times as long as the normal prefix.

[0017] To reduce spectral sidelobes, the cyclic prefixing and windowing block 3 performs windowing on the OFDM symbol by applying a gradual roll-off pattern to the amplitude of the OFDM symbol. The OFDM symbol is input into a digital-to-analogue converter after which it is sent to a transmitter front-end 6 that converts the baseband wave form to the appropriate RF carrier frequency in this particular embodiment for transmission from antenna 7.

[0018] With particular reference to Figure 4, the transmitted OFDM signal is received by an OFDM receiver through an antenna 10. The OFDM signal is processed (down-converted) using the receive circuitry 11. The processed OFDM signal is input into a analog-to-digital converter 12. The digital OFDM signal is received by a symbol timing circuit 13 which acquires the OFDM symbol timing and provides a timing signal to a Fast Fourier Transform (FFT) block 14 and an integrate and dump filter 15. The integrate and dump filter 15 sums K samples that are separated by T seconds. The memory of the filter — which consists of a delay line of M samples, where M is the FFT size — is cleared at the start of each new symbol. This reset time is indicated by the timing circuit 13 which is already present in a normal OFDM receiver to indicate the start of the FFT interval. A control circuit 16 sets the number of averaging intervals K.

[0019] As an alternative implementation, the integrate and dump filter could be placed after the FFT circuit 14 instead of before. In that case, for each symbol, K consecutive FFT outputs are averaged. However, the processing load is increased because the FFT always has to run at the maximum clock rate.

[0020] The sequence of symbols produced by the FFT circuit 14 is applied to conventional decoding circuitry 17 to produce the data output signal.

[0021] When a fallback rate is used at a rate that is K times lower than the original rate, the above described technique will produce subcarriers each of which has a bandwidth that is K times smaller than the original bandwidth. Thus, although the total signal bandwidth does not substantially change, the bandwidth of each subcarrier does become smaller. This makes it possible to do frequency division multiple access of up to K users in

the same band. Each user has to shift its carrier frequency by a different multiple of 1/KT in order to stay orthogonal to the other users. As a example, when 64 subcarriers are used with a subcarrier spacing of 1 MHz, then it is possible to accommodate 4 users in the same channel when using a fallback rate with K=4. All 4 users use the same transmission and reception scheme as described above, but their carrier frequencies have an offset of 0, 250, 500 and 750 KHz, respectively, or, in general, n/KT, where the values of n are different MODULO K.

[0022] As discussed in VN, the control circuits 4, 16 may be responsive to external settings and/or the results of monitoring the signal quality. As also discussed in VN, it may be appropriate to use different modes for the up-links and the down-links in a communications system.

Claims

1. Orthogonal frequency division multiplex communications apparatus employing a set of sub-carriers which are orthogonal over a time T, information-carrying symbols being expressed by superpositions of said sub-carriers,
CHARACTERISED IN THAT
the apparatus is configured to selectively operate in one of a plurality of signalling modes in each of which the duration of each said symbol is KT where K is a positive integer, different ones of the said modes having different values of K but the same set of sub-carriers.

2. Apparatus as claimed in claim 1 wherein one of the said modes has K=1.

3. Apparatus as claimed in claim 1 or claim 2 wherein a guard time is interposed between successive ones of said symbols, the length of said guard time being greater for modes with a greater value of K.

4. Apparatus as claimed in claim 3 wherein the length of said guard time is KT_G where T_G is the same for all of the said modes.

5. Apparatus as claimed in any of the preceding claims, being a receiver and including Fourier transform means (14) for recovering said symbols from said superposition of sub-carriers and averaging means (15) for providing, when operating in a mode in which K>1, an average over K successive periods of duration T.

6. Apparatus as claimed in claim 5 wherein said averaging means (15) are connected upstream of the Fourier transform means (14) to receive the superposition of subcarriers of duration KT and derive an averaged superposition as input to the Fourier transform means (14).

7. Apparatus as claimed in any of claims 1 to 4, being a transmitter and including means (3,4) arranged to receive the superpositions of sub-carriers expressing the symbols and to derive a K-fold repetition of each said superposition.

8. A method of signalling using orthogonal frequency division multiplexing employing a set of sub-carriers which are orthogonal over a time T, information-carrying symbols being expressed by superpositions of said sub-carriers,
CHARACTERISED BY
selecting one of a predetermined plurality of signalling modes in each of which the duration of each said symbol is KT where K is a positive integer, different ones of the said modes having different values of K, but the same set of sub-carriers.

9. A method as claimed in claim 8 wherein one of the said modes has K=1.

10. A method as claimed in claim 8 or claim 9 wherein a guard time is interposed between successive ones of said symbols, the length of said guard time being greater for modes with a greater value of K.

11. A method as claimed in claim 10 wherein the length of said guard time is KT_G where T_G is the same for all of the said modes.

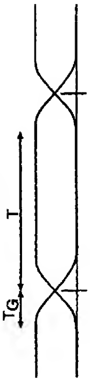


Fig.1.

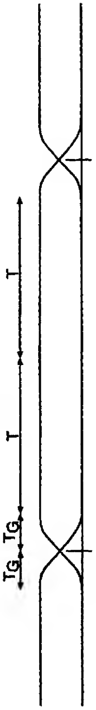


Fig.2.

Fig.3.

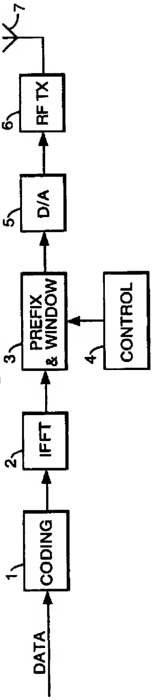
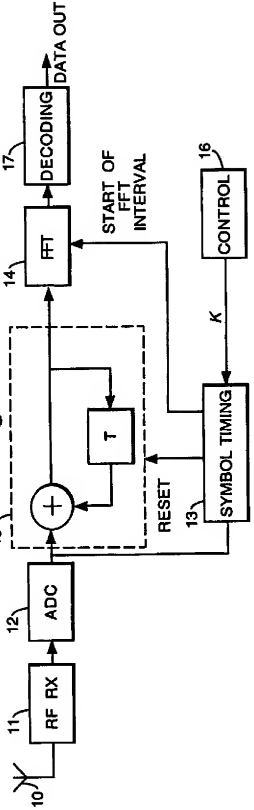

DATA
CODING
1
IFFT
2
PREFIX & WINDOW
3
CONTROL
4
D/A
5
RF TX
6
7

Fig.4.


10
RF RX
11
ADC
12
SYMBOL TIMING
13
FFT
14
15
T
RESET
CONTROL
16
K
START OF FFT INTERVAL
DECODING
17
DATA OUT

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 20 0010.

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	LARSSON ET AL.: "Mixed traffic in a multi carrier system" 1996 IEEE VEHICULAR TECHNOLOGY CONFERENCE, 28 April 1996 - 1 May 1996, NEW YORK, US, pages 1259-1263, XP000593147 * page 1262, right-hand column, paragraph 3 - paragraph 6 *	1,8	H04L27/26 H04L1/12
A	EP 0 589 709 A (MATSUSHITA) 30 March 1994 * page 45, line 20 - line 38 *	1,8	
A	RASMUSSEN ET A.: "A unifying discrete-time model for direct sequence and multicarrier variable rate broadband CDMA" SEVENTH IEEE INTERNATIONAL SYMPOSIUM ON PERSONAL, INDOOR AND MOBILE RADIO COMMUNICATIONS., 15 - 18 October 1996, NEW YORK, US, pages 1111-1115 vol.3, XP002068805 * page 1112, left-hand column *	1,8	TECHNICAL FIELDS SEARCHED (Int.Cl.6)
A	OKADA ET AL.: "Wideband indoor radio system using orthogonal multicarrier modulation" IEEE INTERNATIONAL CONFERENCE ON SYSTEMS ENGINEERING, 17 - 19 September 1992, NEW YORK, US, pages 457-462, XP002068806 * page 457, right-hand column, paragraph 4 *	1,8	H04L

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	19 June 1998	Scriven, P

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

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(71) Applicant:
SUN MICROSYSTEMS, INC.
Palo Alto, California 94303 (US)

(72) Inventors:
- **Johnson, Thomas V.**
Burlington, MA 01803 (US)
- **Davis, James D.**
Pepperell, MA 01463 (US)
- **Ting, Charles C.**
Wayland, MA 07118 (US)

(74) Representative:
Browne, Robin Forsythe, Dr.
Urquhart-Dykes & Lord
Tower House
Merrion Way
Leeds LS2 8PA West Yorkshire (GB)

(54) Web-based enterprise management with multiple repository capability

(57) A transport neutral technique allows an object manager (20) to communicate with a CIM repository (130) using any of a variety of protocols (158, 160). The object manager software (20) is independent of the transport mechanism used and need not be changed if the transport mechanism changes. A computer system (110) to be managed includes a CIM object manager (20) and any number of provider APIs (122) that provide resource information about the computer system. A CIM repository (130) stores classes and instances used by the object manager. A remote application computer (150) runs a software management application (32) that communicates with the object manager of the computer system using a local client API (156). A Repository API of the object manager includes an interface definition (300) defining all methods called by the object manager. Also included is a protocol-specific class that implements the interface definition; there is a protocol-specific class for each protocol desired to be supported. Each class implements methods using a specific protocol. A factory class is executed when the object manager invokes a method call passing in a desired protocol parameter. The factory class creates a protocol-specific object of one of the protocol-specific classes depending on the protocol parameter. The object is returned to the object manager which executes one of its protocol-specific methods thus allowing communication to a repository using a protocol independent of the object manager.

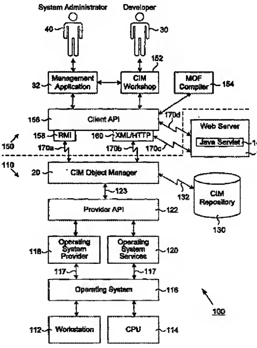


FIG. 2A

Description

FIELD OF THE INVENTION

[0001] The present invention relates generally to managing the resources of a computer system. More specifically, the present invention relates to a technique for communicating database operations from a Common Information Model (CIM) object manager to multiple remote CIM repositories.

BACKGROUND OF THE INVENTION

[0002] Recently, computers and their associated peripheral equipment (a computer system) have become increasing more complex. As such, it has become progressively more and more complicated for a user or system administrator to manage the resources of such a computer system. With a variety of peripheral devices and software applications available for use, and their ever-changing nature, the job of a system administrator has become more difficult. Computer system resources such as attached devices, network connections, software applications, etc., must all be managed to ensure an efficiently working system for the user. Within a large corporation having large numbers of such computer systems spread around the world, the task of managing the resources of each computer system can be daunting.

[0003] Recently, the industry has responded to such a need by introducing Web-Based Enterprises Management (WBEM) which is both an initiative and a technology. As an initiative, WBEM includes a standard for managing systems, networks, users, and applications by using Internet technology. As a technology, WBEM provides a way for management applications to share management data independently of vendor, protocol, operating system, or management standard. By developing management applications according to WBEM principles, vendors can develop products that work together easily at a lower cost of development.

[0004] One known standard for implementation of WBEM is the Common Information Model (CIM). CIM is an approach to managing systems and networks. CIM provides a common conceptual framework to classify and define the parts of a network environment and depict how they integrate. The model captures notions that are applicable to all areas of management, independent of technology implementation.

[0005] WBEM software includes tools and technology that software developers can use to create CIM-compliant software applications that manage the environment of a computer system. Developers can also use this software to write "providers," programs that supply data and events for managed objects that are specific to their domain.

[0006] There can be drawbacks, however, associated with various implementations of WBEM software. For example, it may be necessary for the object manager of a computer system to be able to access different types of databases, whether local or remote. Not all implementations, however, are well-suited for this type of access.

[0007] FIG. 1 illustrates a prior art computer system 10 that has resources to be managed. Resources include disk usage, CPU utilization, running applications, etc. Not shown for simplicity are hardware components of the computer system or other software applications. A CIM object manager 20 is responsible for handling all communication between management applications, a CIM repository 26 and managed objects. In this example, CIM repository 26 is a local drive that communicates via a local connection 28 to object manager 20. A provider application programming interface (API) 22 provides an interface to any needed system information 24 to be provided to object manager 20. Object manager 20 may also access CIM repository 26 over local connection 28 to quickly retrieve data objects that have been previously stored. In this fashion, object manager 20 is well-suited for gathering resource information regarding computer system 10.

[0008] In order to efficiently manage the resources of computer system 10, a software developer 30 writes management application software 32 for managing the resources of the computer system. When in operation, the results of management application 32 may be used by a system administrator 40 to manage the computer system. Client application 32 communicates via a Client API 34 to retrieve resource information from computer system 10. Client API 34 uses any suitable local or remote network connection 36 to access object manager 20.

[0009] Prior art implementations of this sort use a single protocol for communication from object manager 20 to CIM repository 26 over local connection 28. Such an implementation is inflexible in that the object manager commands to repository 26 are dependent upon a single protocol. In other words, the commands are not independent of the protocol; should the protocol be modified or if another protocol be used or desired, it will be necessary to rewrite portions of object manager 20 which would be undesirable.

[0010] In addition, having an object manager that is depended upon a particular protocol presents difficulties when repository 26 is remote from object manager 20. In this scenario, it may be desirable to communicate over a network connection using any of a variety of protocols instead of always being required to use a local protocol. In prior art computer system 10 portions of object manager 20 would have to be rewritten for each and every different protocol that is desired to be used.

[0011] Therefore, a technique is desired that would permit an object manager to communicate both locally and remotely with any number of repositories using any of a variety of protocols. It is desired to implement this technique with the least impact upon developers of

object manager software.

SUMMARY OF THE INVENTION

[0012] To achieve the foregoing, and in accordance with the purpose of the present invention, a technique is disclosed that allows an object manager to communicate with any number of repositories using any of a variety of local or remote protocols. Advantageously, the object manager becomes independent of protocol used and need not be changed if the protocol changes.

[0013] In one embodiment, a method is used for communication between a Common Information Model (CIM) object manager and a CIM repository. The method involves first creating a connection between the object manager the CIM repository. Next, a protocol indicator is passed from the object manager to a repository API. The protocol indicator identifies a protocol by which the object manager desires to communicate with the CIM repository. A protocol-specific object is created having methods implemented using the protocol. Finally, the protocol-specific object is returned to the object manager, thus the object manager may communicate with the CIM repository using the protocol desired.

[0014] In another embodiment, a computer system interacts with a CIM repository on a separate computer. The computer system includes an object manager that has program code for interacting with the CIM repository and a protocol indicator. Also included is a repository application programming interface (repository API) that has a factory class arranged to receive the protocol indicator from the object manager and produce a protocol-specific object. Also within the repository API is a first class having methods defined thereon implemented in a first protocol and a second class having methods defined thereon implemented in a second protocol. Thus, the protocol-specific object may be returned to the object manager for use in communicating with the CIM repository using a desired protocol.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The invention, together with further advantages thereof, may best be understood by reference to the following description taken in conjunction with the accompanying drawings in which:

FIG. 1 illustrates a prior art computer system that has managed resources.

FIGS. 2A and 2B illustrate a Web-Based Enterprise Management (WBEM) architecture suitable for implementing an embodiment of the invention.

FIGS. 3A and 3B illustrate an example graphical user interface for the CIM workshop of FIG. 2.

FIG. 4 illustrates an interface definition useful for implementing an embodiment of the invention.

FIG. 5 illustrates an implementation definition for the interface of FIG. 4.

FIG. 6 illustrates another implementation definition for the interface of FIG. 4.

FIG. 7 is a JAVA factory class definition.

FIG. 8 is a flowchart illustrating a store or retrieve repository method issued by an object manager to a CIM repository.

FIGS. 9 and 10 illustrate a computer system suitable for implementing embodiments of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0016] FIGS. 2A and 2B illustrate a Web-Based Enterprise Management (WBEM) architecture suitable for implementing an embodiment of the invention. Architecture 100 includes computer system 110 having resources to be managed, and application computer 150 where management applications are developed and run. Computer system 110 may be any suitable computer having resources needing to be managed such as CPU load, disk space, installed applications, etc. The hardware layer includes workstation 112 and CPU 114. Workstation 112 may be any suitable computer workstation such as the SPARC workstation from Sun Microsystems, Inc. CPU 114 may be any suitable processor such as an Intel processor. The software layer of computer system 110 includes operating system 116 (other software applications not shown for simplicity) which may be any suitable operating system such as the Solaris operating system from Sun Microsystems, Inc.

[0017] The object provider layer of computer system 110 includes operating system provider 118, operating system services 120 and provider application programming interface (API) 122. The provider layer communicates with operating system 116 via interface 117, for example, by using a JAVA Native Interface (JNI). Object providers act as intermediaries between CIM object manager 20 and one or more managed devices. When object manager 20 receives a request from a management application 32 for data that is not available in CIM repository 130 it forwards the request to a provider. Object providers are installed on the same machine as object manager 20. Object manager 20 then uses provider API 122 to communicate with locally installed providers. Providers are classes that perform various functions in response to a request from object manager 20. For example, providers map information from a managed device to a CIM JAVA class and map

information from a CIM JAVA class to a managed device format.

[0018] Provider API 122 is an API used by various provider programs to communicate information about managed objects to object manager 20. Operating system provider 118 is a collection of JAVA classes or native methods that represent the operating environment of computer system 110. Operating system services 120 also provide logging information from operating system 116 to object manager 20.

[0019] A variety of other providers may also be present. For example, an SNMP provider includes JAVA classes that map CIM data to SNMP data. Also, a CPU-specific provider may be used to transport resource information directly between CPU 114 and provider API 122, thus bypassing operating system 116.

[0020] Providers may be categorized into three types according to the requests they service. An instance type supplies dynamic instances of a given class and supports the retrieval, enumeration, modification and deletion operations. A property type supplies dynamic property values, for example, disk space. A method type supplies methods of one or more classes. A single provider can support both methods and instances. Most providers are "pull" providers which mean they maintain their own data, generating it dynamical if necessary. Pull providers have minimal interaction with object manager 20 and CIM repository 130. The data managed by a pull provider typically changes frequently, requiring the provider to either generate the data dynamically or retrieve it from a local cache whenever an application issues a request. A single provider can act simultaneously as a class instance and method provider by proper registration and implementation of all relevant methods.

[0021] The management layer of computer system 110 includes CIM object manager 20, CIM repository 130 and web server software 140. Object manager 20 may be any suitable WBEM compliant manager. Object manager 20 manages CIM objects that are represented internally as JAVA classes. Client computers running management applications (such as application computer 150) connect to object manager 20 for resource information about computer system 110. When a WBEM client connects to object manager 20 it receives a reference to that object manager. The client can then perform WBEM operations using this reference.

[0022] When management application 32 uses client API 156 to request or update information about a managed object, object manager 20 contacts either the appropriate provider for that object or a suitable persistent storage mechanism such as repository 130. In one embodiment, classes that are handled by a provider have a "provider" qualifier that identifies the provider to contact for the class. When object manager 20 receives a request for a class that has a "provider" qualifier, it routes the request to the specified provider. If no provider is specified it routes the request to repository 130 using JAVA Naming and Directory Interface (JNDI) 132.

[0023] Object manager 20 also performs various start-up functions: starting and registering the RMI server; registering the XML server; setting up a connection to repository 130; and waiting for incoming requests. Object manager 20 also performs other normal operations: performing security checks such as authentication and authorization; performing syntactical and semantic checking of CIM data operations; routing requests to providers or persistent storage; and delivering data from providers or from persistent storage to client management applications.

[0024] CIM repository 130 is a central storage area for CIM class and instance definitions that communicates with object manager 20 via connection 132. Connection 132 may be any suitable local connection within computer system 110, or may be a remote connection. Connection 132 may use any suitable protocol. Further details on communication with repository 130 are provided in FIG. 2B and in FIGS. 4-8.

[0025] Web server software 140 may be any suitable WBEM XML-compliant web server such as the Sun Web Server available from Sun Microsystems, Inc. JAVA servlet 142 converts XML data to the client API format. For example, if management application 132 contains XML data, client API client 156 encodes the data as XML messages and transports the encoded messages to web server 140 that is running JAVA servlet 142. Web server 140 listens for XML messages on a standard port and passes control to servlet 142 when detected. Servlet 142 then decodes the XML messages it receives. Servlet 142 then converts the XML data to the client API format and transmits the information back to client API 156 in RMI format. Alternatively, should object manager 20 support the HTTP format, client API 156 may communicate directly to object manager 20 without the need for web server 140.

[0026] The application layer of WBEM architecture 100 includes management application 32, CIM workshop 152, MOF compiler 154 and client application programming interface (API) 156. In this embodiment of the invention, these elements of the application layer are shown running on application computer 150 (other hardware and software not shown for simplicity). Alternatively, application computer 150 and computer system 110 may be the same computer or the elements of the application layer may reside on a variety of computers and not exclusively on application computer 150.

[0027] A software developer 30 uses any suitable software tool to develop a management application 32 for processing and displaying data from managed objects of computer system 110. Management application 32 uses client API 156 to request information about managed objects from object manager 20. In this fashion, analysis of the resources of computer system 110 can be presented to a system administrator 40 for proper action.

[0028] Client API 156 and provider APIs represent

and manipulate CIM objects. These APIs represent CIM objects as JAVA classes. An object is a computer representation or model of a managed resource of computer system 110 such as a printer, disk drive or CPU. A developer uses the CIM specification to describe managed objects and to retrieve information about managed objects in computer system 110. One advantage of modeling managed resources using CIM is that those objects can be shared across any system that is CIM compliant.

[0029] Management application 32 may be any of a wide variety of software applications written to analyze and manage the resources of computer system 110. By way of example, management application 32 manages system aspects such as disk information (space available, partitions, etc.), CPU load, event processing, date, time, time zone, memory available, ports, etc.

[0030] Application 32 may also manage specific devices of the computer system such as disks, tape drives, modems, other I/O devices, NICs, and network aspects of the system such as TCP/IP, Netbeui, Novell, etc. Further, management application 32 manages the software applications running on computer system 110 by determining what is currently running on the system, what is currently installed, the state of installation, which applications can be terminated, performing application metering, managing application life cycle, process management, user management, etc.

[0031] In one embodiment of the invention, developer 30 uses a CIM workshop 152 written in JAVA for viewing, changing, adding and deleting CIM classes and instances. CIM workshop 152 provides a graphical user interface for the developer. For example, developer 30 may view and select namespaces, may add namespaces, add properties, qualifiers and methods to new classes, view and create instances, and view and modify instance values. Developer 30 may also use CIM workshop 152 to browse a class inheritance tree and change the root of an object tree for a namespace.

[0032] MOF compiler 154 pares files created in the Managed Object Format (MOF), converts files to JAVA class and stores the extracted classes and instances in repository 130. The MOF language is a syntax for defining CIM classes and instances and is described in the CIM specification. Although classes and instances can also be added through client API 156 using JAVA, MOF compiler 154 eliminates the need to write such code. Compiler 154 provides developers and administrators with a simple and fast technique for modifying repository 130.

[0033] In one embodiment, client API 156 is a public API that JAVA applications use to request operations from object manager 20. Client API 156 is used by management application 32 to transfer data to and from object manager 20. Client API 156 includes a variety of classes, instances and methods useful for communicating with object manager 20 using any suitable transport mechanism.

[0034] Preferably, Client API 156 is an application programming interface used by management application 32 to communicate with object manager 20 using Remote Method Invocation (RMI) protocol 158 or XML over an HTTP protocol 160 according to the techniques described in U.S. patent application No. ________ (Atty Docket SUN1P366) referenced above. Other suitable protocols may also be used such as COM from Microsoft Corporation. Client API 156 may communicate directly with object manager 20 using RMI or may communicate using the XML/HTTP protocol using web server 140. Alternatively, client API 156 can communicate using the XML/HTTP protocol 160 directly should object manager 20 support the HTTP format.

[0035] Connections 170a-170d are any suitable local or network connection between computer system 110 and application computer 150. By way of example, these connections occur over an internet, an intranet, an extranet, within a workgroup, or other.

[0036] FIG. 2B illustrates further detail in which CIM object manager 20 communicates with any of a variety of remote CIM repositories using a repository API 180. In this embodiment, each of repositories 190, 192 and 194 are located remotely from object manager 20 and computer system 110. In this example each repository is located on a different computer although it is conceivable that all may be located on a single computer, or that a repository is local to computer system 110.

[0037] Repository 190 is a database implemented using a flat file technique or object serialization in JAVA; it communicates with Repository API 180 over a network connection 132a that uses simple JAVA code protocol. Repository 192 is an object-oriented database and may be implemented using tools such as those available from Sybase, Oracle, or Informix. Repository 812 communicates with Repository API 180 over a network connection 132b using a JAVA Database Connectivity (JDBC) protocol. Repository 194 is a Lightweight Directory Access Protocol (LDAP) type of database that communicates over network connection 132c using a JAVA Naming Directory Interface (JNDI) protocol.

[0038] Repository API 180 is used by object manager 20 to store data to, or retrieve data from, the repositories. Repository API 180 includes a variety of classes, instances and methods useful for communicating with the repositories using any suitable protocol. Preferably, Repository API 180 communicates with the repositories using a JAVA language protocol, a JDBC protocol, a JNDI protocol, an LDAP protocol, an ODBC protocol, or other protocols suitable for use with a database. Implementation of such communication between object manager 20 and the repositories according to an embodiment of the invention is further described in FIGS. 4-8.

[0039] FIGS. 3A and 3B illustrate an example graphical user interface for CIM workshop 152. Preferably, a login to the workshop prompts for a host name,

namespace, user name and password. By default, workshop 152 connects to the object manager on the local host in the default namespace. FIG. 3A illustrates CIM classes that represent objects in the selected namespace on the selected host. Listed in panel 210 are the objects of the selected namespace. On the right-hand panel are shown the properties 212 for the selected object (in this case the object "Solaris Package") and methods 214 (not shown). FIG. 3B shows all instances of a selected object. Instances are shown in the left-hand panel, and in this example instance 252 is shown. The right-hand panel shows all properties 254 associated with the selected instance and its associated methods 256 (not shown).

[0040] FIG. 4 illustrates an interface definition 300 of Repository API 180 useful for implementing an embodiment of the invention. Interface 300 lists various methods that may be called by object manager 20 in the course of database operations with repositories 190-194. Advantageously, this interface may be implemented using a variety of classes having protocol-specific methods thus allowing a transport neutral object manager to be written. Interface 300 includes an interface name 302 which in this example is "CIM Repository API." Included are a variety of methods defined for the interface. Each method has a method name 304, a return value 306 and parameters 308. By way of example, shown is one method "Add CIM Element" 310 having a return value of "void" and accepting parameters "element" and "namespace." A large number of other methods may be defined for interface 300

[0041] By way of example, these methods include the following. The Create Namespace method creates a CIM namespace, a directory containing classes and instances. (When a management application connects to object manager 20 it specifies a namespace. All subsequent operations occur within that namespace on the object manager host.) The method Delete Class deletes the specified class. The method Delete Instance deletes the specified instance. The method Delete Qualifier deletes the specified qualifier. The method Enumerate Classes retrieves the specified classes from a repository. The method Enumerate Namespace gets a list of namespaces. The method Enumerate Instances gets of list of instances for the specified class. The method Enumerate Qualifier Types get a list of qualifier types for the specified class. The method Get Class gets the CIM class for the specified CIM object path. The Get Instance method gets the CIM instance for the specified CIM object path.

[0042] The method Get Qualifier Type gets the qualifier type for the specified CIM object path. The method Set Instance invokes a repository to add or update the specified CIM instance to the specified namespace. Other methods may also be included within interface 300 such as Add Aliased Class Name, Add Aliased Instance Name, Get Aliased Class Name, Get Aliased Instance Name, etc.

[0043] Once interface 300 has been defined it is possible to then code protocol-specific methods to implement each of the methods defined in interface 300. In this fashion, any number of protocol-specific classes are provided each having an implementation for a specific protocol such as JDBC or LDAP. Though the use of these protocol-specific classes, object manager 20 is able to communicate with any CIM repository using any suitable protocol in a transparent fashion.

[0044] FIG. 5 illustrates an implementation definition 400 for the interface of FIG. 4. Specifically, implementation 400 implements class "CIM Repository API" using methods specific to the LDAP protocol. Such protocol-specific methods allow object manager 20 to communicate via Repository API 180 to repository 194 using the LDAP protocol. Implementation 400 includes a class name 402 "CIM Repository LDAP." Also included is constructor definition code 404 that constructs an instance of class 402 that is specific to the LDAP protocol. Use of a constructor definition to create an instance is well known to those of skill in the art.

[0045] Also included in implementation 400 are the specific implementations of the methods defined upon interface 300. For each method implemented there is a method name 406, a return value 408, parameters 410 and implementation code 412. Implementation code 412 is preferably JAVA code that implements the particular method using any constructs necessary that are specific to the RMI protocol. Those of skill in the art will appreciate how to implement JAVA code for a particular purpose that must adhere to a specific protocol.

[0046] Preferable, all of the methods defined upon interface 300 are implemented in implementation 400. Shown by way of example is the method Add CIM Element 416 which has a return value of "void" and accepts the parameters element and namespace. Not shown for simplicity is the actual LDAP-specific JAVA code that implements the method Add CIM Element. The other methods defined in interface 300 are also listed in implementation 400 along with their LDAP-specific code.

[0047] FIG. 6 illustrates an implementation definition 500 for the interface of FIG. 4. Specifically, implementation 500 implements class "CIM Repository API" using methods specific to the JDBC protocol. Such protocol-specific methods allow object manager 20 to communicate via Repository API 180 to repository 192 using the JDBC protocol. Implementation 500 includes a class name 502 "CIM Repository JDBC." Also included is constructor definition code 504 that constructs an instance of class 502 that is specific to the JDBC protocol. Use of a constructor definition to create an instance is well known to those of skill in the art.

[0048] Also included in implementation 500 are the specific implementations of the methods defined upon interface 300. For each method implemented there is a method name 506, a return value 508, parameters 510 and implementation code 512. Implementation code

512 is preferably JAVA code that implements the particular method using any constructs necessary that are specific to the JDBC protocol. Those of skill in the art will appreciate how to implement JAVA code for a particular purpose that must adhere to a specific protocol.

[0049] Preferable, all of the methods defined upon interface 300 are implemented in implementation 500. Shown by way of example is the method Add CIM Element 516 which has a return value of "void" and accepts the parameters element and namespace. Not shown for simplicity is the actual JDBC-specific JAVA code that implements the method Add CIM Element. The other methods defined in interface 300 are also listed in implementation 500 along with their JDBC-specific code.

[0050] FIG. 7 is a JAVA factory class 600. Factory 600 is used for determining which protocol is desired by object manager 20 and directing the creation of a protocol-specific object to be returned to the object manager.

[0051] Factory 600 includes a class name 602 "CIM Repository Factory" and any number of defined methods. For each method there is a method name 604, a return value 606, parameters 608 and an implementation 610. In particular, the method Get Repository API accepts the parameters protocol, namespace and version, and returns an instance of interface 300 which is a protocol-specific instance of either implementation 400 or implementation 500. Of course, other protocol-specific objects may be returned if other implementations are defined. The implementation code 610 for method 612 may be any suitable JAVA code that checks the protocol parameter to see which protocol is desired and then directs either implementation 400 or 500 to construct a new instance of itself. By way of example, a series of case statements may be used. Other methods may also be defined and implemented within factory 600.

OBJECT MANAGER EXECUTION

[0052] FIG. 8 is a flowchart illustrating invocation of a method by the object manager to perform a database operation such as storing or retrieving an object. Once management application 32 has been created by developer 30 and the classes and methods of FIGS. 4-7 have been defined, the object manager may perform operations on one of the repositories using any desired protocol. FIG. 8 illustrates a single method call according to one embodiment of the invention.

[0053] In step 702 management application 32 creates a connection from application computer 150 to computer system 110. Preferably, application 32 invokes a method within Client API 156 which creates an instance of application 32 within object manager 20. Application 32 passes to the method a host name, a namespace, a user name, a password, and the protocol by which it is desired to communicate with host computer system 110. Any suitable network protocol may be identified such as RMI, XML/HTTP or DCOM.

[0054] In step 704 object manager 20 receives a method call from application 32 that requires a database operation. The method call is preferably performed using the technique described in U.S. patent application No. 09/333,878. In response to this method call, object manager 20 identifies a repository and protocol and makes a call to Repository API 180.

[0055] In step 706 factory 600 of Repository API 180 checks the protocol desired by object manager 20 using its method Get Repository API. This method returns a protocol-specific object which is an instance of either the class defined in implementation 400 or the class defined in implementation 500. For example, in step 710 if the protocol parameter is LDAP, then in step 714 the constructor definition 404 of implementation 400 executes and results in an LDAP-specific object having LDAP-specific methods being returned to the object manager. On the other hand, if the protocol parameter is JDBC, then in step 722 the constructor definition 504 of implementation 500 executes and produces a JDBC-specific object which is returned to the object manager. As shown in steps 726 and 730, a desire for use of simple JAVA protocol results in a JAVA-specific object being returned. Other protocols are also supported. In step 738 object manager 20 invokes a desired database method upon the protocol-specific object recently returned. Because the methods of this object are specific to the protocol desired by object manager 20, communication between Repository API 180 and the target repository occurs using the desired protocol in a fashion transparent to application 32 and to object manager 20.

[0056] Once the target CIM repository has processed the method (which may be a request for an object, a request to add an object, etc.), then in step 742 the result is returned from the repository to object manager 20 via Repository API 180 using the desired protocol. In this fashion, a technique has been described that allows an object manager to be written independent of the protocol by which it is desired to communicate with a target CIM repository.

COMPUTER SYSTEM EMBODIMENT

[0057] FIGS. 9 and 10 illustrate a computer system 900 suitable for implementing embodiments of the present invention. FIG. 9 shows one possible physical form of the computer system. Of course, the computer system may have many physical forms ranging from an integrated circuit, a printed circuit board and a small handheld device up to a huge super computer. Computer system 900 includes a monitor 902, a display 904, a housing 906, a disk drive 908, a keyboard 910 and a mouse 912. Disk 914 is a computer-readable medium used to transfer data to and from computer system 900.

[0058] FIG. 10 is an example of a block diagram for computer system 900. Attached to system bus 920 are

a wide variety of subsystems. Processor(s) 922 (also referred to as central processing units, or CPUs) are coupled to storage devices including memory 924. Memory 924 includes random access memory (RAM) and read-only memory (ROM). As is well known in the art, ROM acts to transfer data and instructions uni-directionally to the CPU and RAM is used typically to transfer data and instructions in a bi-directional manner. Both of these types of memories may include any suitable of the computer-readable media described below. A fixed disk 926 is also coupled bi-directionally to CPU 922; it provides additional data storage capacity and may also include any of the computer-readable media described below. Fixed disk 926 may be used to store programs, data and the like and is typically a secondary storage medium (such as a hard disk) that is slower than primary storage. It will be appreciated that the information retained within fixed disk 926, may, in appropriate cases, be incorporated in standard fashion as virtual memory in memory 924. Removable disk 914 may take the form of any of the computer-readable media described below.

[0059] CPU 922 is also coupled to a variety of input/output devices such as display 904, keyboard 910, mouse 912 and speakers 930. In general, an input/output device may be any of: video displays, track balls, mice, keyboards, microphones, touch-sensitive displays, transducer card readers, magnetic or paper tape readers, tablets, styluses, voice or handwriting recognizers, biometrics readers, or other computers. CPU 922 optionally may be coupled to another computer or telecommunications network using network interface 940. With such a network interface, it is contemplated that the CPU might receive information from the network, or might output information to the network in the course of performing the above-described method steps. Furthermore, method embodiments of the present invention may execute solely upon CPU 922 or may execute over a network such as the Internet in conjunction with a remote CPU that shares a portion of the processing.

[0060] In addition, embodiments of the present invention further relate to computer storage products with a computer-readable medium that have computer code thereon for performing various computer-implemented operations. The media and computer code may be those specially designed and constructed for the purposes of the present invention, or they may be of the kind well known and available to those having skill in the computer software arts. Examples of computer-readable media include, but are not limited to: magnetic media such as hard disks, floppy disks, and magnetic tape; optical media such as CD-ROMs and holographic devices; magneto-optical media such as floptical disks; and hardware devices that are specially configured to store and execute program code, such as application-specific integrated circuits (ASICs), programmable logic devices (PLDs) and ROM and RAM devices. Examples of computer code include machine code, such as produced by a compiler, and files containing higher level code that are executed by a computer using an interpreter.

[0061] Although the foregoing invention has been described in some detail for purposes of clarity of understanding, it will be apparent that certain changes and modifications may be practiced within the scope of the appended claims. For instance, the application computer and the computer system to be managed may be the same computer, or may be separated by a great distance. Also, the various CIM repositories may be located along with the computer system, may each be remotely located on a separate computer, or may be remotely located on a single computer. The use of a web server may not be required should the CIM object manager support the HTTP format. Other types of classes and methods may be used while not departing from the spirit of the invention. Therefore, the described embodiments should be taken as illustrative and not restrictive, and the invention should not be limited to the details given herein but should be defined by the following claims and their full scope of equivalents.

Claims

1. A method for communication between a Common Information Model (CIM) object manager of a host computer and a CIM repository, said method comprising:

creating a connection between said object manager and said CIM repository;

passing a protocol indicator from said object manager to a repository application programming (API), said protocol indicator identifying a protocol by which said CIM object manager desires to communicate with said CIM repository;

creating a protocol-specific object having methods implemented using said protocol; and

returning said protocol-specific object to said CIM object manager, whereby said CIM object manager may communicate with said CIM repository using said protocol.

2. The method of claim 1 further comprising:

invoking a method defined upon said protocol-specific object;

transmitting said method using said protocol over said connection to said CIM repository; and

returning a result to said CIM object manager over said connection using said protocol.

3. The method of claim 1 wherein said protocol is LDAP, JDBC, or JAVA.

4. The method of claim 1 wherein said CIM repository is resident on said host computer.

5. The method of claim 1 wherein said CIM repository is resident on a separate computer.

6. The method of claim 1 wherein said creating a protocol-specific object includes

   calling a JAVA factory class.

7. A computer system for interacting with a CIM repository database, said system comprising:

   a CIM object manager including a protocol indicator and program code for interacting with said CIM repository; and

   a repository application programming interface (repository API) including

      a factory class arranged to receive said protocol indicator from said object manager and produce a protocol-specific object,

      a first class having methods defined thereon implemented in a first protocol, and

      a second class having methods defined thereon implemented in a second protocol, whereby said protocol-specific object may be returned to said object manager for use in interacting with said CIM repository.

8. The system of claim 7 wherein said CIM object manager is arranged to receive a method call from a management application using the protocol identified by said protocol indicator.

9. The system of claim 7 wherein said CIM repository is resident on said computer system.

10. The system of claim 7 wherein said computer system and said CIM repository are connected over a network connection implemented in the protocol identified by said protocol indicator.

11. The system of claim 7 wherein the protocol identified by said protocol indicator is LDAP, JDBC or JAVA.

12. The system of claim 7 further comprising:

   a plurality of CIM repositories, each repository arranged to communicate with said CIM object manager using a different protocol.

13. The system of claim 12 wherein each repository is resident on a different computer.

14. A computer-readable medium comprising computer code for communication between a Common Information Model (CIM) object manager of a host computer and a CIM repository, said computer code of said computer-readable medium effecting the following:

   creating a connection between said object manager and said CIM repository;

   passing a protocol indicator from said object manager to a repository application programming (API), said protocol indicator identifying a protocol by which said CIM object manager desires to communicate with said CIM repository;

   creating a protocol-specific object having methods implemented using said protocol; and

   returning said protocol-specific object to said CIM object manager, whereby said CIM object manager may communicate with said CIM repository using said protocol.

15. The computer-readable medium of claim 14 further comprising computer code for effecting the following:

   invoking a method defined upon said protocol-specific object;

   transmitting said method using said protocol over said connection to said CIM repository; and

   returning a result to said CIM object manager over said connection using said protocol.

16. The computer-readable medium of claim 14 wherein said protocol is LDAP, JDBC or JAVA.

17. The computer-readable medium of claim 14 wherein said creating a protocol-specific object includes

   calling a JAVA factory class.

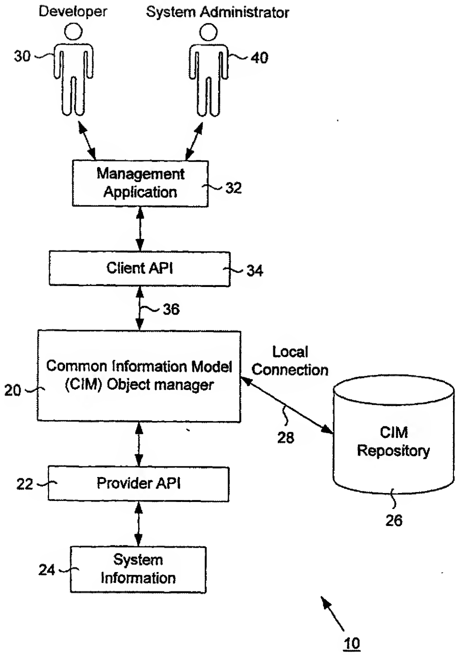


FIG. 1
(Prior Art)

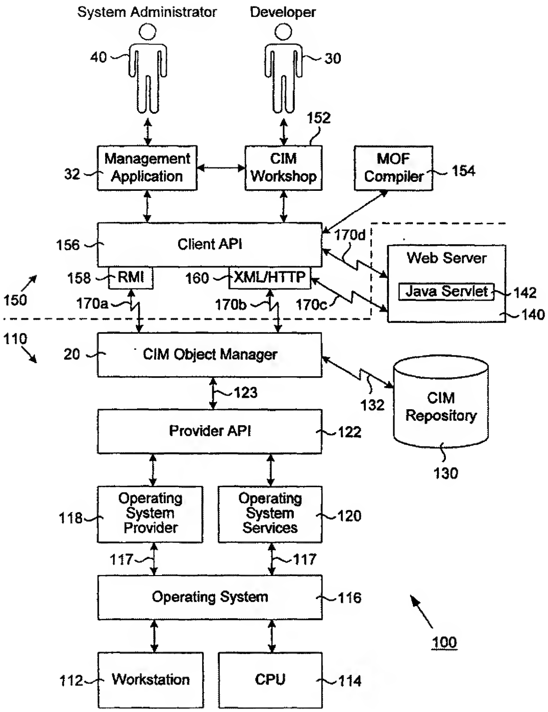

System Administrator
Developer
40
30
152
Management Application
32
CIM Workshop
MOF Compiler
154
156
Client API
170d
Web Server
158
RMI
160
XML/HTTP
Java Servlet
142
150
170a
170b
170c
140
110
20
CIM Object Manager
123
132
CIM Repository
Provider API
122
130
Operating System Provider
118
Operating System Services
120
117
117
Operating System
116
100
112
Workstation
CPU
114

FIG. 2A

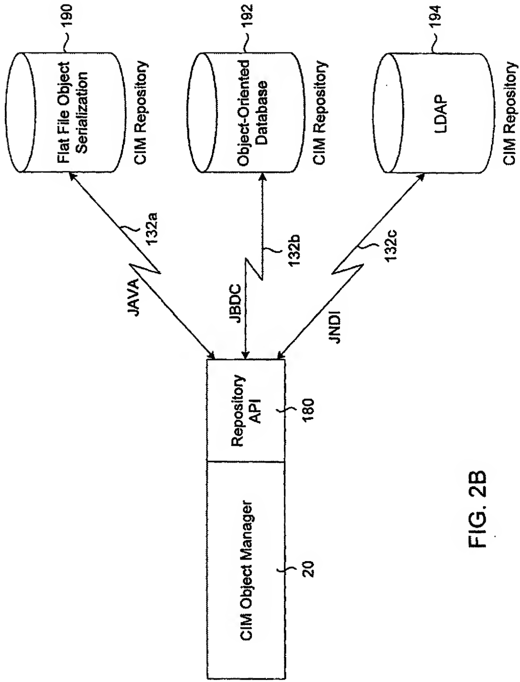
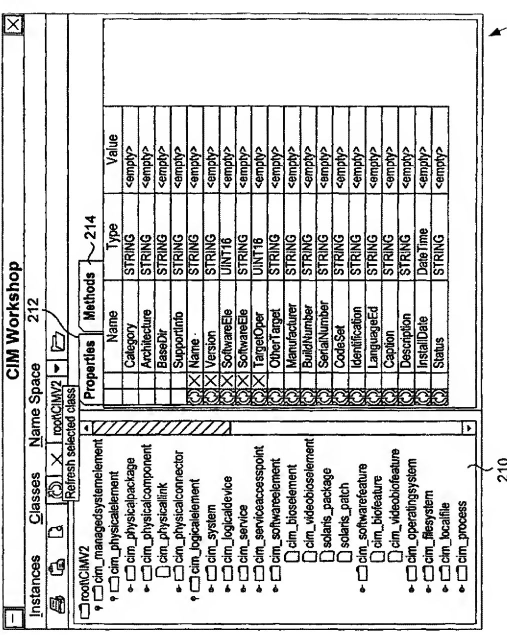

Flat File Object Serialization
CIM Repository
190
Object-Oriented Database
CIM Repository
192
LDAP
CIM Repository
194
132a
132b
132c
JAVA
JBDC
JNDI
Repository API
180
CIM Object Manager
20

FIG. 2B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Refresh selected class
Properties
Methods
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SupportInfo
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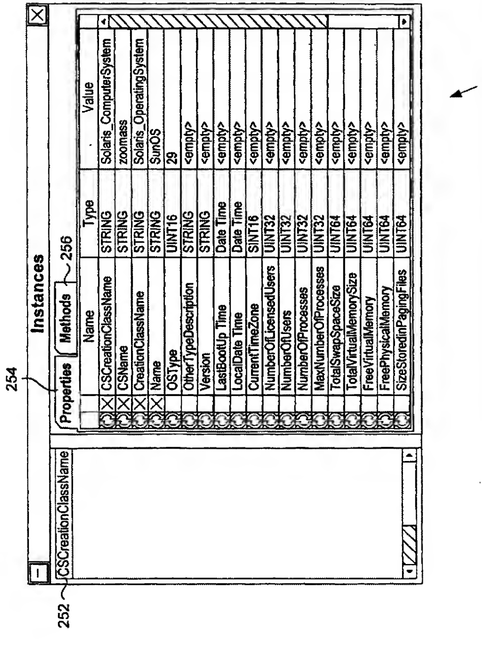
cim_physicalcomponent
cim_physicallink
cim_physicalconnector
cim_logicalelement
cim_system
cim_logicaldevice
cim_service
cim_serviceaccesspoint
cim_softwareelement
cim_bioselement
cim_videobioselement
solaris_package
solaris_patch
cim_softwarefeature
cim_biofeature
cim_videobiofeature
cim_operatingsystem
cim_filesystem
cim_localfile
cim_process
210

200

FIG. 3A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Properties
Methods
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256
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TotalVirtualMemorySize
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FreeVirtualMemory
UINT64
<empty>
FreePhysicalMemory
UINT64
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SizeStoredinPagingFiles
UINT64
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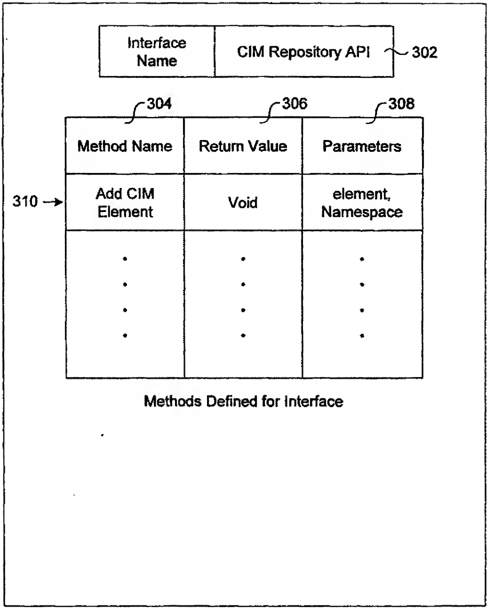
250

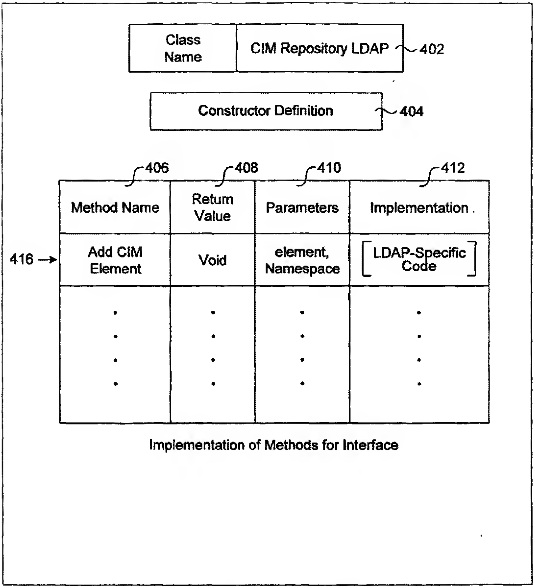
FIG. 3B



Interface Definition

300

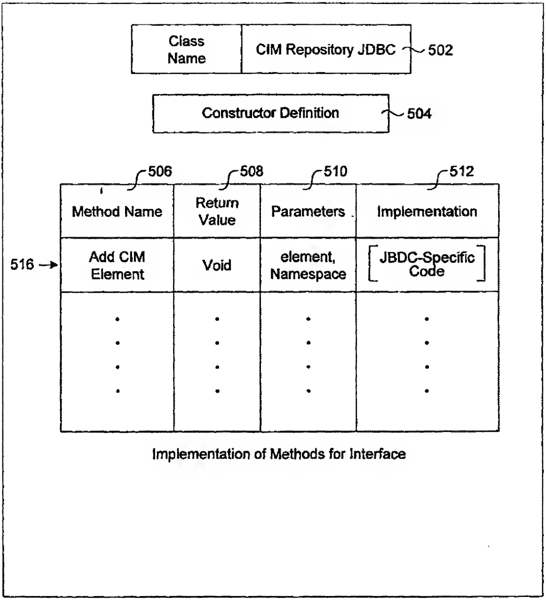
FIG. 4



Implementation Definition for Interface

400

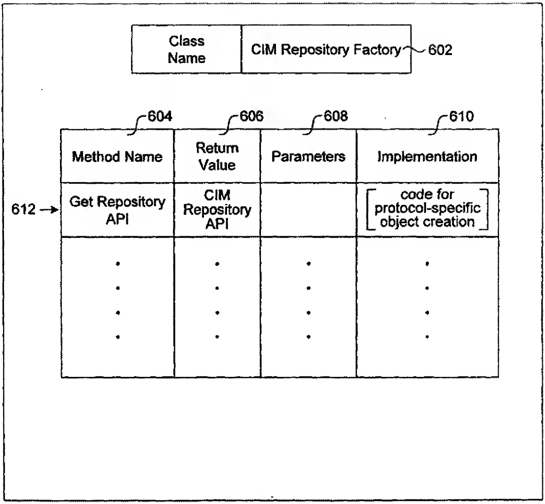
FIG. 5



Implementation Definition for Interface

500

FIG. 6



Factory

600

FIG. 7

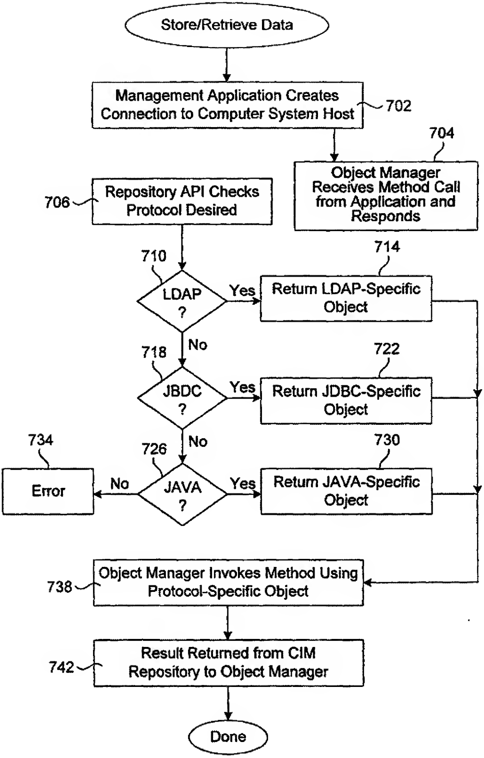

Store/Retrieve Data
Management Application Creates Connection to Computer System Host
702
704
Object Manager Receives Method Call from Application and Responds
706
Repository API Checks Protocol Desired
710
LDAP ?
Yes
714
Return LDAP-Specific Object
No
718
722
JBDC ?
Yes
Return JDBC-Specific Object
734
No
726
730
Error
No
JAVA ?
Yes
Return JAVA-Specific Object
738
Object Manager Invokes Method Using Protocol-Specific Object
742
Result Returned from CIM Repository to Object Manager
Done

FIG. 8

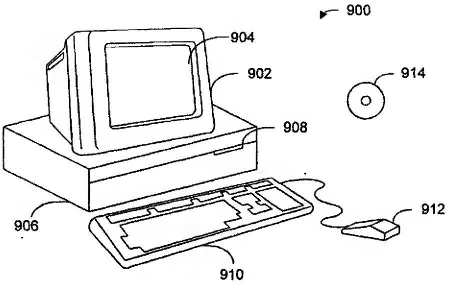

900
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FIG. 9

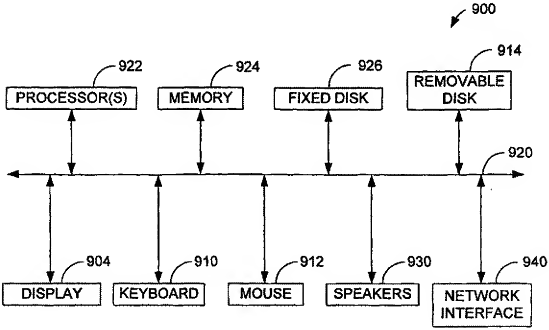
900
922
PROCESSOR(S)
924
MEMORY
926
FIXED DISK
914
REMOVABLE DISK
920
904
DISPLAY
910
KEYBOARD
912
MOUSE
930
SPEAKERS
940
NETWORK INTERFACE

FIG. 10

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(71) Applicant: **ALCATEL**
75008 Paris (FR)

(72) Inventors:
- **Sestito, Vincenzo**
  20127 Milano (IT)
- **Licata, Giuseppa**
  20090 Segrate (Milano) (IT)
- **Mazzini, Andrea**
  20060 Pessano con Bornago (Milano) (IT)

(74) Representative: **Colombo, Stefano Paolo et al**
Alcatel, Intellectual Property Department,
Vimercate Via Trento, 30
20059 Vimercate (MI) (IT)

(54) Method of managing time-slot interchange in transoceanic MS-spring networks

(57) A method of managing time slot interchange in transoceanic MS-SP ring networks. The method, in case of ring failure in a single span of the path installed in a transoceanic MS-SP RING with Time Slot Interchange (TSI) mechanism, comprises the step of carrying out a ring switch action by the MS-SP mechanism, and is characterized by comprising the step of re-routing the path in the time slot of the low-priority (LP) channels corresponding to the time slot of the high-priority (HP) channels of the failured span. The method according to the invention further provides for the managing of double-failure or multi-failure cases resulting in one or more nodes being isolated.

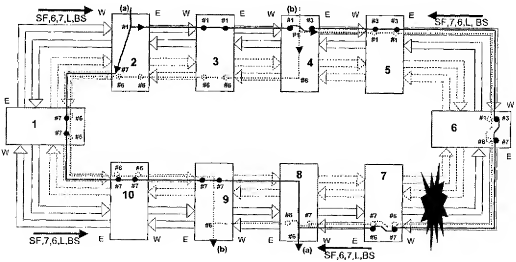

Fig. 3

EP 1 185 015 A2

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Description

[0001] The present invention relates to a method of managing changes of time-slot allocations in ring networks protected by a transoceanic MS-SPRING protection mechanism.

[0002] In SDH MS-SPRING (Multiplex Section Shared Protection Ring) networks, a shared protection mechanism is implemented, which mechanism allows for the automatic restoration of the traffic in case of defects or failures in the connection fibers. In other words, the MS shared protection ring networks perform the automatic restoration of the traffic through a synchronized re-routing of said traffic, performable at each node of the ring. This operation is controlled by a protocol consisting of messages that are continuously interchanged between adjacent nodes. Said protocol and the related operations are defined by several international standards issued by ANSI, ITU-T and ETSI and they are characterized by a set of rules and messages. See, for instance, Recommendation ITU-T G. 841.

[0003] Protection in an MS shared protection ring network is implemented according to a so-called Bridge and Switch technique that consists essentially in re-routing the traffic, by means of an appropriate modification in the internal connections of the network elements, switching it from the working capacity to the protection capacity. The protection in an MS shared protection ring network is a multiplex section-oriented protection mechanism, i.e. the events defining the traffic restoration and the hierarchy that regulates those events are given at multiplex section level. In the "classic" (or terrestrial) MS shared protection rings, in the event of a failure, the whole high-priority line capacity is re-routed by utilizing the corresponding low-priority line capacity; in the transoceanic MS shared protection rings, on the contrary, only the paths affected by a failure are selectively re-routed.

[0004] It is also known that the ring networks provide for a mechanisms termed "Time Slot Interchange", in short TSI. TSI means, for instance, that when traffic is configured in a given ring network, such a traffic, which is carried in the associated STM-n and hence in the AU-4 contained in the STM-n, is allowed to travel through a network element occupying different AU-4 numbers at the input and at the output. Consider for instance a maximum capacity of a four-fiber ring, composed of sixteen AU-4s. The TSI mechanism allows one to enter a network element (of pure transit and where no termination occurs) with AU-4#X from its West side (W) and to go out from its East side (E) with an AU-4#Y, where $X \neq Y$ = 1, 2, ..., 16. The advantage is a greater flexibility in the traffic allocation and a very efficient exploitation of the band.

[0005] At present, performing TSI in ring networks protected by an MS-SPRING protection mechanism is not known. In particular, it is not known to perform allocation changes in transoceanic MS shared protection ring networks.

[0006] Therefore the main object of the present invention is to provide a method allowing the execution of allocation changes in transoceanic rings protected by an MS-SPRING mechanism. This and further objects are achieved by a method having the features set forth in independent claim 1 and a network element according to claim 8. The respective dependent claims define further advantageous characteristics of the invention itself. All the claims are intended to be an integral part of the present description.

[0007] The basic idea of the present invention consists substantially in protecting the high-priority traffic by assigning, in case of a ring failure, the low-priority channel time slots chosen according to the real failure location and to the instant at which such failure has occurred, with respect to other failures possibly already present.

[0008] The invention will certainly become clear in view of the following detailed description, given by way of a mere non limiting and exemplifying example, wherein:

- Fig. 1 shows a ring network in a stable faultless situation, the network having a plurality of nodes, two installed paths and some allocation changes;
- Fig. 2 shows the same ring network of Fig. 1 just after a ring failure took place;
- Fig. 3 shows the ring network of Fig. 2 in a stable situation with a ring failure;
- Figs. 4 show the signaling that is received/generated by the single nodes and the corresponding actions performed in the event of simultaneous double failure;
- Figs. 5 show the signaling that is received/generated by the single nodes and the corresponding actions performed in the event of nearly simultaneous double failure;
- Figs. 6 show the signaling that is received/generated by the single nodes and the corresponding actions performed in the event of double failure at different times (first sub-scenario);
- Figs. 7 show the signaling that is received/generated by the single nodes and the corresponding actions performed in the event of double failure at different times (second sub-scenario);
- Figs. 8 show the signaling that is received/generated by the single nodes and the corresponding actions performed in the event of clearing of a first failure; and
- Figs. 9 show the signaling that is received/generated by the single nodes and the corresponding actions performed in the event of clearing of a second failure.

[0009] In the various figures, a four-fiber transoceanic telecommunication ring has been always depicted. The two working fibers (otherwise known as "high-priority channels" or "HP channels") are indicated by solid-line

arrows whereas the protection fibers (otherwise known as "low-priority channels" or "LP channels") are indicated by dashed-line arrows. Naturally, the present invention applies both to the illustrated case of bi-directional traffic and to the case of unidirectional traffic.

[0010] Moreover, the present invention is applicable also to rings in which the traffic subjected to TSI is configured with "channel concatenation (AU4)".

[0011] The ring illustrated to describe the invention comprises ten network elements or nodes, represented by blocks and designated by respective numerals (1 to 10). The West (W) and East (E) sides of each node are indicated. The term "span" is used throughout this description to mean that part between two adjacent nodes, for instance between nodes 1 and 2 or the one between nodes 7 and 8.

[0012] In the ring there are depicted, by way of a non-limiting example, two paths installed, "path (a)" and "path (b)". The first path (path a) is depicted by a bolt solid line whereas the second path (path b) is depicted by a bolt dotted line. Path (a) is inserted at node 2 and is dropped at node 8. Path (b) is inserted at node 4 and is dropped at node 9.

[0013] Finally, it has been tried to clearly indicate (with numbers after symbol "#") the various time slots in which the various paths are allocated, span by span. Thus it has been also indicated if a Time Slot Interchange (TSI) occurs at a node or if that node allows that path to transit without changing the AU-4 on which it is allocated.

[0014] The present invention contemplates the general criteria set forth below:

I) single failure: once a ring failure has occurred in a given span, a ring switch action is performed by the MS shared protection mechanism. This activity defines the set of re-routable paths, namely all the paths whose nominal route includes the failured span. According to the present invention, each of these paths is re-routed on the time slot of the low-priority (LP) channels corresponding to the time slot of the high-priority (HP) channels of the failured span. There is no risk of any conflict since the LP time-slot assignment criterion is the same for all the failured paths.

II) double failure: if a failure occurs at a further span and the path can still be saved, then

II.I) i) the actual re-routing is released; ii) among the two failured spans one is chosen according to a certain criterion; and iii) the path is re-routed over the time slot of the low-priority (LP) channels corresponding to the time slot of the high-priority (HP) channels of the selected failured span. Should multiple (more than two) failures occur, the choice of the span to consider for the TSI path protection is to be made by selecting, according to the above criterion, among the spans adjacent to the switching nodes that are able to communicate with the termination nodes of the path to be protected. There is no risk of any conflict since the LP time-slot assignment criterion is the same for all the paths affected by the failure. In this way, any transient misconnection is avoided.

II.II) The actual re-routing is not released when the persistency of the re-routing information is supported by the ring network elements.

[0015] The procedures that are implemented by each node of the ring (in addition to the procedures already provided for by the MS shared protection mechanism) will be indicated below:

A. If, at both W and E sides of the node, two Bridge Requests with an "Idle" status code concerning the same span (single failure) are detected, then each path comprising the span in question is re-routed over the LP time slot equal to the HP time slot of the (sole) span affected by the failure. In other words, if the node is a path termination node (a node where the path to be re-routed is inserted or dropped), the Bridge & Switch action is performed by utilizing the LP time slot equal to the HP time slot of the span affected by the failure.

A1. If at W or E side of the node at least one Bridge Request with an "Idle" status code is detected, a pass-through is performed, if necessary, by utilizing the same LP time slot (LP time slot equal to the HP time slot of the span affected by the failure).

B. If at both W and E sides of the node Ridge Requests with a "Bridged and Switched" status code concerning different spans (multiple failures) are detected, then each path comprising the spans in question is re-routed over the LP time slot equal to the HP time slot of the span affected by the failure that has been chosen according to a fixed criterion. The criterion for selecting one among the failed spans could, for instance, be any one of the following:

a) the failed span adjacent to the switching node with higher (or lower) node identification is chosen;

b) the failed span adjacent to the switching node coming first (or last) in the ring map; or

c) the failed span adjacent to the switching node that is "far West" or "far East" node in the ring.

[0016] Similarly to the above case A, if the node in question is a path termination node (node in which the path to be re-routed is inserted or dropped), the Bridge & Switch action is performed by utilizing the LP time slot equal to the HP time slot of the selected failured span.

B1. If at the W or E side of the node at least one

Bridge Request with "Bridged and Switched" status code is detected, a pass-through is performed, if necessary, by utilizing the same LP time slot as above.

C. In an optimized embodiment, should a path re-routing due to single failure be under way, if at W and E sides of the node Bridge Requests with a different ("Idle" or "Bridged and Switched") status code that carry the indication of a second failure, hence located at a different span, are detected, then, for each path that has already been re-routed, it is evaluated if the new requests exhibit a failured state that requires to release or maintain the present re-routing. It is not necessary to release the actual re-routing of a single path in the following cases:

i) when a failure is detected in addition to the already existing failure/s (and such new failure/s does/do not result in the "isolation" condition of any of the termination nodes of the already protected path); or ii) when the last occurred span failure has been removed.

[0017] It is understood how the persistency of the path re-routing condition is strictly connected to the coexistence of the aforesaid triggers at both sides of the nodes. This behavior results in the correct re-routing of the failured paths, namely it prevents misconnections from being created during transient states of the ring protection mechanism.

[0018] Note that the above is applicable to the case of bi-directional path and unidirectional one not using the inverse route. Clearly, if two unidirectional paths are allocated on the same time slot (in opposite directions), then the same LP time slot can be assigned to both paths.

[0019] Fig. 1 shows a transoceanic MS shared protection ring protected against failures in accordance with the invention, at some nodes of the ring Time-Slot Interchange (TSI) occurring. The installed paths are two: (a) and (b). Path (a) enters the ring at node 2 and is allocated on the AU-4 #1; therefore, in span 2-3 the allocation is AU-4#1; at node 3 the allocation is unchanged (therefore it remains AU-4#1); at node 4, the allocation is changed from AU-4#1 to AU-4#3; in span 4-5 the allocation is therefore AU-4#3; at node 5 the allocation is not changed (therefore it remains AU-4#3); in span 5-6 the allocation is therefore AU-4#3; at node 6 the allocation is changed from AU-4#3 to AU-4#7; therefore, in span 6-7 the allocation is AU-4#7; at node 7 the allocation changes again from AU-4#7 to AU-4#6; therefore, in span 7-8 the allocation is AU-4#6; finally, path (a) is dropped at node 8. For path (b): it enters at node 4 and is allocated on AU-4#1; this allocation is maintained up to node 6 where it changes from AU-4#1 to AU-4#6; it is changed again at node 7 (passing from AU-4#6 to AU-4#7) and at node 8 (passing from AU-4#7 to AU-4#6). Finally, path (b) is dropped at node 9.

[0020] In the event of a ring failure (namely, a failure that makes both high-priority (HP) channels and low-priority (LP) channels useless), the present invention provides for a method of remedying such failure notwithstanding the presence of allocation changes in the ring. Reference should be made, for the event of single ring failure, to Figs 2 and 3 where a ring failure in the span 6-7 has been simulated.

[0021] As it is known, the management of failures in the synchronous (SDH or SONET) telecommunications networks occurs, for some protection types among which the MS-SPRING one, through bytes K1 and K2 of the frame overhead. Since the present invention does not concern specifically such bytes K1 and K2, a more precise description thereof will not be given, the reader having the possibility to refer to relevant Recommendations, for instance the ITU-T Recommendation G. 841, incorporated herein by reference.

[0022] In the event of a failure, the nodes (6 and 7) that are adjacent to the failure will send, as usual, proper failure signaling in the direction opposite to the failure. The structure of the request (APS signaling) is the following: Bridge Request, Destination Node ID, Source Node ID, Type of Path, Protection Status. In this instance, the node 6 will send a signaling of the type SF, 7,6,L,ID (Signal Fail, Destination Node: 7, Source Node: 6, Path: Long, Protection Status: Idle) to indicate that a ring failure occurred at span 6-7 and that no action has been taken for the time being. Node 7 will do the same by sending a signaling type SF,6,7,L,ID from its East side (E).

[0023] Such signaling will travel down the ring in opposite directions and will be received by termination nodes (2, 8; 4, 9) of paths (a) and (b) that will perform the requested Bridge and Switch (BR & SW) by utilizing the LP channels. In accordance with the present invention, the ring protection (BR&SW and pass-through), in the event of single ring failure, is performed by squelching the terminations of LP traffic allocated on the AU-4s corresponding to the failured span and by allocating the HP traffic on such AU-4s. With reference to Fig. 3, since in span 6-7 the path (a) was allocated on the HP AU-4#7 and the path (b) was allocated on the HP AU-4#6, the allocation AU-4#7 (of the LP channels) will be utilized for the first path and the allocation AU-4#6 (of the LP channels) will be utilized for the second path.

[0024] Should TSI be configured also on low-priority traffic, the high-priority traffic protection that requires the use of one of the LP channels utilized in the low-priority TSI, will anyway result in the squelching action on both the low-priority traffic terminations.

[0025] Once a node adjacent to the failure has received the signaling sent by its homologous opposite side, with Protection Status corresponding to "Idle", the node itself will send a modified signaling (with Protection Status = Bridged & Switched, BS). In other words, node 6 will send SF,7,6,L,BS from its West side whereas node

7 will send SF,6,7,L,BS from its East side. Upon restoration of the full ring functionality (fault clearing) the BR&SW will be removed and the failure signaling (SF, 7,6,L,BS and SF,6,7,L,BS) will be removed.

[0026] The present invention, in addition to the single failure event illustrated above, provides for a traffic protection method applicable to multiple failures leading to isolation of one or more nodes in which the TSI of the installed path/s is configured. Within this context three failure scenarios are considered and separately described: in the first scenario the failures occur simultaneously, in the second scenario the failures occur nearly simultaneously while in the third scenario the failures occur at different times.

[0027] Referring initially to Figs. 4, consider the case where two failures (SF1 and SF2) occur exactly at the same time instant. For simplicity, paths (a) and (b) before the occurrence of the failures, are allocated in a manner similar to what described for Fig. 1 and therefore the description of the allocations will not be repeated here. Upon the occurrence of the first failure (SF1) on the span 6-7, the node 6 (Fig. 4.1) will send a failure signaling (SF,7,6,L,ID) from the West side whereas, upon the second failure (SF2) on the span 7-8, node 8 will send a simultaneous failure signaling (SF,7,8,L,ID) from the East side (Fig. 4.2).

[0028] At the time when each of the two signaling with "Idle" code, which were generated by the switching nodes, is received by the termination nodes of the paths to be protected, squelching of the local termination (if any) of the LP channel corresponding to the HP channel allocated in the failed span to which the signaling is referred, takes place; while, at the nodes designed to realize the pass-through of the LP channels, the squelching of the local termination (if any) of the LP channel corresponding to the HP channel allocated in the failed span to which the signaling is referred takes place and the subsequent pass-through connection also takes place. The actions just described (squelching and squelching + pass-through) are removed both from the path termination nodes and from the pass-through nodes, as soon as such nodes receive the second signaling generated by the switching nodes.

[0029] When (Fig. 4.3) the signaling (SF,7,6,L,ID) containing the "Idle" code of SF1 reaches node 8, node 8 (Fig. 4.4) will send a signaling containing BR&SW (BS) Status Code of the type SF,7,8,L,BS. The same will be for node 6 (Fig. 4.5): as soon as it receives signaling (SF,7,8,L,ID) containing the "Idle" code of SF2, it will send a signaling containing BR&SW Status Code (BS) of the type SF,7,6,L,BS.

[0030] At the time when one of the two signalings with BS code generated by switching nodes is received by the termination nodes of the HP paths to be protected, the squelching of the local termination (if any) of the LP channel to be used for the protection, that was chosen according to one of the criteria described above, takes place; while, at the nodes designed to realize the pass-through of the LP channels, the squelching of the local termination (if any) of the same LP channel will take place and also the subsequent pass-through connection, will take place.

[0031] The Bridge & Switch action that is performed on the LP channel chosen according to the same criterion as above, is performed by every termination node of the HP paths to be protected, as soon as both signalings with BS Code (SF,7,6,L,BS and SF,7,8,L,BS) are detected at the two sides of the node itself.

[0032] Thus, a stable state of the protected ring has been achieved.

[0033] Referring initially to Figs. 5, consider the case where two failures (SF1 and SF2) occur nearly at the same time instant (or anyway failure SF2 occurs before the situation following SF1 is stabilized). For simplicity, paths (a) and (b) before the occurrence of the failures, are allocated similarly to what described for Fig. 1 and therefore the description of the allocations will not be repeated here. Upon the occurrence of the first failure (SF1) in span 6-7, the node 6 will send a failure signaling (SF,7,6,L,ID) from the West side and, similarly, it will send another failure signaling (SF,6,7,L,ID) from East side. See Figs. 5.1 and 5.2.

[0034] Suppose (Fig. 5.3) that the failure signaling (SF,6,7,L,ID) from the East side is able to reach node 8 before the second failure (SF2) occurs in span 7-8, which results in node 7 isolated. Upon the second failure (SF2), node 8 (node adjacent to the failure) will send a corresponding failure signaling (SF,7,8,L,ID) from its East side. Anyway, the signaling of the second failure will follow the first failure one (Fig. 5.4).

[0035] As soon as the signaling (SF,6,7,L,ID; SF, 7,6,L,ID) containing the "Idle" code of the first failure reach the termination node 2 (Fig. 5.5) of path (a), this node will perform the BR&SW action by utilizing the LP AU-4 corresponding to the span affected by the first failure (LP AU-4#7, in this instance). However, as soon as also the new signaling (SF,7,8,L,ID) of the second failure (SF2) reaches node 2, the BR&SW action, just realized, is removed (Fig. 5.6).

[0036] Analogously (Fig. 5.7), as soon as the signaling (SF,6,7,L,ID; SF,7,6,L,ID) containing the "Idle" code of the first failure reach the termination node 4 of the path (b), this node will perform the BR&SW action by utilizing the LP AU-4 corresponding to the span affected by the first failure (LP AU-4#6 in this case). However, as soon as also the new signaling (SF,7,8,L,ID) relating to the second failure (SF2) reaches node 4, the BR&SW action, just realized, is removed (Fig. 5.8).

[0037] Obviously, the actions to be taken before the just described temporary BR&SWs are the squelching of the local termination (if any) of the LP channel associated with the span 6-7 both on the termination nodes of the paths to be protected, and on the nodes designed to realize the pass-through, as well as the pass-through connection of the LP channel itself: in order a node to perform such actions, the reception of at least one of the

two signaling with "Idle" code generated by the switching nodes is enough to the interested node.

[0038] At the same time, when the signaling (SF,7,6,L, ID) containing the "Idle" code of the first failure reaches node 8, node 8 will send a signaling containing the BR&SW (BS) status code of the type SF,7,8,L,BS (Fig. 5.9). The same will be for node 6: as soon as it receives the signaling (SF,6,7,L,ID) containing the "Idle" code of the first failure, it will send a signaling containing the BR&SW (BS) Status Code of the type SF,7,6,L,BS (Fig. 5.10).

[0039] Because of the presence of the new signaling (SF,7,8,L,ID) concerning the second failure (SF2), node 6 will change again its signaling from SF,7,6,L,BS to SF, 7,6,L,ID (Fig. 5.11).

[0040] At this stage both the signaling transmitted by node 8 containing the BR&SW Status Code and the two consecutive signaling transmitted by node 6 respectively containing the BS&SW (BS) and the "Idle" status codes are present in the ring. The signaling containing the BS Status Code result, at the nodes detecting them, in the squelching of the local termination (if any) of the LP channel chosen for the protection according to one of the aforesaid criteria (for instance the LP channel corresponding to the allocation used in the span affected by the first failure, AU-4#6), as well as in the pass-through of such LP channel at the nodes designed to perform such a function. It is to be noted that, among the two signaling that consecutively emitted by node 6, the one containing "Idle" code does not remove the squelching and pass-through actions activated by the previous signaling (with BS code), since both refer to the same failed span: SF,7,6,L,BS and SF,7,6,L,ID.

[0041] The node 9 (Fig. 5.12), receiving a signaling with BS code (SF,7,6,L,BS and SF,7,8,L,BS) from both its W and E sides, will perform the BR&SW action by utilizing the LP allocation related to one of the failured spans, for instance the one affected by the first failure (AU-4#6). Node 8, that receives the signaling containing the BS code (SF,7,6,L,BS) previously sent to it by node 6, will realize the BR&SW action (Fig. 5.13) by utilizing the LP allocation related to one of the failured spans, for instance the one affected by the first failure (AU-4#7). Some of the possible selection criteria have been mentioned above.

[0042] Since the request that reaches both node 9 and node 8 with "Idle" code, is related to the failured span already indicated in the preceding request (SF, 7,6,L,BS), the BR&SW action is maintained (Fig. 5.14).

[0043] When the request related to the second failure (SF2) and containing the BS code reaches node 6, the APS signaling is updated with the BS code, namely node 6 will send, from side W, the signaling SF,7,6,L,BS (Fig. 5.15).

[0044] Node 4, as soon as it receives signaling with BS code from both sides, will realize the BR&SW action by utilizing the LP allocation related to one of the spans affected by a failure, for instance the one affected by the first failure (AU-4#6).

[0045] Lastly, the node 2, as soon as it receives, from both its W and E sides, a signaling with BS code (SF, 7,6,L,BS and SF,7,8,L,BS), will perform the BR&SW action (Fig. 5.16) by utilizing the LP allocation related to one of the spans affected by a failure, for instance the one affected by the first failure (AU-4#7).

[0046] Thus, a stable state in the protected ring is obtained.

[0047] As said above, the scenario of the actions taken by the various nodes is different in the case where the failures do not occur at the same time. In this connection, two different sub-scenarios should be distinguished. With reference to Figs 1 to 3 and 6, the actions and the consequences related to the first sub-scenario are schematically listed below starting from a situation free of faults.

[0048] The first failure (SF1) occurs. The node 6 sends SF,7,6,L,ID from the W side. The node 7 sends SF,6,7,L,ID from the side E (Fig. 2).

[0049] SF,7,6,L,ID and SF,6,7,L,ID reach the termination nodes of paths (a) and (b). The termination nodes perform the BR&SW action for each path to be protected by utilizing the corresponding LP channels of the span affected by SF1. Path (a) is allocated on LP AU-4#7. Path (b) is allocated on LP AU-4#6 (Fig. 3).

[0050] The nodes 6 and 7 adjacent to the failure SF1 send respective signaling with BS code (SF,7,6,L,BS and SF,6,7,L,BS) and a stable scenario of ring protected against SF1 is obtained (Fig. 3).

[0051] SF2 occurs on span 7-8: node 7 is isolated (Fig. 6.1). Node 8 sends SF,7,8,L,ID from the side E (Fig. 6.2).

[0052] The BR&SW action (both the BR&SW and the pass-through at the intermediate nodes) performed for path (a) is removed (Figs. 6.3 and 6.4). The BR&SW action (both the BS&SW and the pass-through at the intermediate nodes) performed for path (b) is removed (Figs. 6.5 and 6.6).

[0053] Node 6 receives the signaling SF,7,8,L,ID and sends SF,7,6,L,ID (Fig. 6.7).

[0054] The node 8 receives from node 6 the signaling SF,7,6,L,ID and sends SF,7,8,L,BS (Fig. 6.8).

[0055] Node 6 receives the signaling SF,7,8,L,BS and sends SF,7,6,L,BS (Fig. 6.9).

[0056] Nodes 2 and 8 receive the signaling SF,7,8,L, BS and SF7,6,L,BS and perform the BR&SW action by utilizing for instance the LP channels with AU-4 corresponding to that of the first failed span (LP AU-4#7). The scenario becomes stable for the path (a) (Figs. 6.10 and 6.11).

[0057] Nodes 4 and 9 receive the signaling SF,7,8,L, BS and SF,7,6,L,BS and perform the BR&SW action by utilizing for instance the LP channels with AU-4 corresponding to the one of the first failed span (LP AU-4#6). The scenario becomes stable for path (b) (Figs. 6.12, 6.13).

[0058] The squelching actions of the local termination

(if any) of the LP channel chosen for the protection according to one of the criteria already described and the subsequent pass-through of the same LP channel at the intermediate nodes come before the BR&SW actions just described and are performed with the rules already pointed out for the two previous scenarios.

[0059] With reference to Figs. 1 to 3 and 7, the actions and the consequences related to the second sub-scenario of double failure at different times will now be schematically listed in the following, still starting from a faultless situation.

[0060] The first failure (SF1) occurs. Node 6 sends SF,7,6,L,ID from the W side. Node 7 sends SF,6,7,L,ID from the E side (Fig. 1).

[0061] SF,7,6,L,ID and SF,6,7,L,ID reach the termination nodes of the paths (a) and (b). The termination nodes perform the BR&SW action for each path to be protected by utilizing the corresponding LP channels of the span affected by SF1. The path (a) is allocated on LP AU-4#7. The path (b) is allocated on LP AU-4#6 (Fig. 2).

[0062] The nodes 6 and 7 adjacent to failure SF1 receive the signaling with ID code (SF,7,6,L,ID and SF, 6,7,L,ID), send respective signaling with BS code (SF, 7,6,L,BS and SF,6,7,L,BS) and a stable scenario of ring protected against SF1 is obtained (Fig. 3).

[0063] SF2 occurs in span 7-8: node 7 is isolated (Fig. 7.1). Node 8 sends SF,7,8,L,ID from the E side (Fig. 7.2).

[0064] The node 8, as a node adjacent to the failure and as a termination node, evaluates whether the already protected paths can still be protected. In the affirmative, no action is taken; in the negative, the BR&SW action is removed (Fig. 7.3).

[0065] Node 9 receives the SF,7,8,L,ID request and evaluates whether the already protected paths can still be protected. In the affirmative, no action is taken; in the negative, the BR&SW action is removed (Fig. 7.4).

[0066] Node 2 receives the SF,7,8,L,ID request and evaluates whether the already protected paths can still be protected. In the affirmative, no action is taken; in the negative, the BR&SW action is removed (Fig. 7.5).

[0067] Node 4 receives the SF,7,8,L,ID request and evaluates whether the already protected paths can still be protected. If yes, no action is taken; if not, the BR&SW action is removed (Fig. 7.6).

[0068] As soon as node 6 receives the SF,7,8,L,ID signaling, it updates its request by inserting the "Idle" status code, of the type SF,7,6,L,ID. After a further signaling exchange, the nodes adjacent to the failure update the respective signaling by inserting "BR&SW" (BS) status code.

[0069] At this point only signaling with BS code are traveling in the ring that is failured by SF1 and SF2 and therefore a stable scenario for paths (a) and (b) towards the failures SF1 and SF2 has been achieved.

[0070] It will be recognized that the first sub-scenario results in a rather simple implementation since it is not necessary to store the failure "history" but, at the same time, traffic is not safeguarded in an optimal manner because the BR&SW is always removed. On the contrary, the second sub-scenario safeguards the traffic in a better manner but it is more difficult to be implemented because the traffic "history" shall be stored.

[0071] Having analyzed in detail the single-failure and the double-failure situations (simultaneous, nearly simultaneous or at different times), we will go on in describing schematically the actions that each network node must perform (and the corresponding consequences) when the failures are cleared and the ring functionality is restored.

[0072] Start from a stable situation of two failures SF1, SF2: in this situation, node 7 is isolated (Fig. 8.1) and only signalings with BS code (SF,7,8,L,BS and SF,7,6,L, BS) are traveling in the ring. Consider to clear first SF1: the node 7, no longer isolated, begins to send the APS signaling with "Idle" code related to the span affected by a failure (SF2) still present between the nodes 8 and 7 (SF,8,7,L,ID) (Fig. 8.2).

[0073] Since the LP allocation of the span 7-6 had been chosen, the BR&SW (and squelching of the any local termination of the LP channel utilized) action at node 4 must be removed. Similarly, as soon as also the SF,8,7,L,ID signaling reaches the other path termination nodes (2, 9, 8), the BR&SW and any local squelching action is removed also at such nodes 2, 9, 8 (Figs. 8.3 to 8.5). The removal of "BR&SW" at the termination nodes is accompanied by the removal of the pass-through (and of any local squelching) from the intermediate nodes that have performed the pass-through of the LP channel heretofore utilized for the protection. Since the signalings present at the intermediate nodes are related to the same span affected by a failure, such nodes can perform, if required, the pass-through of the LP channels, related to the current failure, to be utilized for the path protection.

[0074] The node 8, as a node adjacent to the failure SF2, receives SF,8,7,L,ID and changes the code of its signaling from SF,7,8,L,BS to SF,7,8,L,ID (Fig. 8.6). Such signaling with ID code gradually reaches all the termination nodes (9, 2, 4) showing them in this way that a single failure (SF2) is present. The termination nodes in turn will execute the BR&SW action (Figs. 8.8 to 8.10) by utilizing the LP channels that correspond to the failured span (for path (a) the LP AU-4#6 will be utilized, for path (b) the LP AU-4#7 will be utilized).

[0075] The nodes (7, 8) adjacent to the failure still present (SF2) will send corresponding signaling with BS code (SF,8,7,L,BS and SF,7,8,L,BS) and a single-failure stable condition will be achieved (Figs. 8.11, 8.12).

[0076] As soon as also SF2 is cleared, the ring will reach the faultless stable condition (Figs. 8.13, 8.14), with the progressive removal of the "Bridge" and "Switch" actions from all the path termination nodes and the consequent signalings with "No Request, Idle" code (NR,9,8,S,ID and NR,6,7,S,ID) by all the ring nodes, including nodes (7, 8) adjacent to the just cleared failure

(SF2).

[0077] Start now from a stable situation of two failures SF1, SF2 (Fig. 9.1): in this situation node 7 is isolated and only signalings with BS code (SF,7,8,L,BS and SF, 7,6,L,BS) are traveling in the ring. Consider to clear SF2 first: node 7 (Fig 9.2), no longer isolated, begins to send the APS signaling with "Idle" code (SF,6,7,L,ID) related to the span affected by failure (SF1) still present between nodes 6 and 7.

[0078] Since just the LP allocation of the span 7-6 had been chosen, the BR&SW action at node 8 can be maintained (Fig. 9.3). Similarly, the SF,6,7,L,ID signaling reaches the other path termination nodes (9, 2, 4) but the BR&SW action is maintained also at such nodes 9, 2, 4 (Figs. 9.4 to 9.6).

[0079] The same processing is carried out at intermediate nodes that perform the pass-through of the LP channels used for the protection: the pass-through is maintained.

[0080] Finally, also node 6 adjacent to the failure SF1 receives SF,6,7,L,ID and will send the corresponding signaling with ID code (SF,7,6,L,ID), reaching a stable scenario with "BS" signalings all over the ring.

[0081] As soon as also SF1 is cleared, the ring will reach the faultless stable condition, with the progressive removal of the "Bridge" and "Switch" actions from all the path termination nodes and the consequent signaling with "No Request, Idle" code (NR,5,6,S,ID and NR, 8,7,S,ID) issued by all the ring nodes, including nodes (6, 7) adjacent to the just cleared failure (SF2). See Figs. 9.7 and 9.8.

[0082] In view of the above detailed description, relating to some cases of single or double failure, the person skilled in the art can easily devise the actions that every node must perform in the event of a failure on other spans and/or in the case where more than two failures occur. Naturally, the present invention is applicable to all these cases and its scope covers all these cases and is limited only by the following claims.

[0083] As far as the practical realization is concerned, it will be understood that all the actions performed by every node or network element are the known Pass-Through, Bridge and Switch, squelching of any terminations of the Low-Priority channels involved in the protection and transmission of signaling, substantially of known type, actions. Therefore, the implementation of the present method does not require to change the physical structure of the existing network elements used in ring networks protected against possible failures. Any modifications must be carried out at level of consequent actions performed by the nodes affected by the protection mechanism, according to signalings already provided for and present in the standardized protocol and on the ground of ring map information, already provided for and processed, as well as traffic map that carries the allocation time-slot information, in every ring span of the single path that is installed.

[0084] Finally it is pointed out that, although the present invention has been described in detail with reference to SDH synchronous transmission, it applies, in similar manner, to other types of synchronous transmission, typically SONET. The fact that this type of signals has not been taken into account in the description shall not be interpreted as a limitation but merely as an example and in order to render the description clear. Therefore, for the purposes of the present description and of the annexed claims, the terminology used for SDH transmissions will include at least the corresponding SONET terminology and shall be read in this perspective.

Claims

1. Method of re-routing a path in a transoceanic MS shared protection ring network in the event of a failure on a span of said path, said ring network comprising network elements connected in a ring configuration by fiber spans, said fiber spans comprising high-priority (HP) channels and low-priority (LP) channels, said method comprising the step of performing a ring switch action by the MS shared protection mechanism, **characterized in that** a time slot interchange mechanism (TSI) is provided in said ring network and **in that** said method comprises the step of re-routing the path over the time slot of the low-priority (LP) channels corresponding to the time slot of the high-priority (HP) channels of the span affected by the failure.

2. Method according to claim 1, in which a further span of the path becomes affected by a failure, **characterized by** comprising the steps of: i) releasing the present re-routing that was performed because of the first failured span; ii) selecting one of the failured spans; and iii) re-routing the failured path over the time slot of the low-priority (LP) channels corresponding to the time slot of the high-priority (HP) channels of the failured span that has been selected.

3. Method according to claim 1, in which a further span becomes affected by a failure, **characterized by** comprising the step of maintaining the re-routing action, performed because of the first failured span, should the persistency of the re-routing information be supported by the network elements of the ring network.

4. Method according to claim 2, **characterized in that** the step of selecting one of the failured spans comprises the step of considering the two spans adjacent to the switching nodes that are able to communicate with the termination nodes of path to be protected in the case where at least one further span of the path becomes affected by a failure.

5. Method according to any of claims 2 to 4, **characterized in that** the step of selecting one of the failured spans comprises the step of selecting the failured span adjacent to the switching node having higher or lower node identification ID.

6. Method according to any of claims 2 to 4, **characterized in that** the step of selecting one of the failured spans comprises the step of selecting the failured span adjacent to the switching node that comes first or last in the network ring map.

7. Method according to any of claims 2 to 4, **characterized in that** the step of selecting one of the failured spans comprises the step of selecting the failured span adjacent to the far west (W) or far east (E) switching node in the ring network.

8. Network element of a transoceanic MS shared protection ring network, said ring network comprising other network elements connected each other in a ring configuration by fiber spans, said fiber spans comprising high-priority (HP) channels and low-priority (LP) channels, said network element comprising means for performing ring switch actions, namely pass-through, bridge or switch actions, upon reception of corresponding signalings and means for generating and sending proper signalings in response to reception of corresponding signalings, a path being installed in said ring network, **characterized in that** a time slot interchange mechanism (TSI) is provided in said ring network and **in that** said network element comprises means for, in case of failure in a span of the installed path, re-routing the path over the time slot of the low priority (LP) channels corresponding to the time slot of the high priority (HP) channels of the failured span.

9. Network element according to claim 8, in which a further span of the path becomes affected by a failure, **characterized by** comprising: i) means for releasing the re-routing action performed because of the first failured span; ii) means for selecting one of the failured spans; and iii) means for re-routing the path over the time slot of the low priority (LP) channels corresponding to the time slot of the high-priority (HP) channels of the failured span which has been selected.

10. Network element according to claim 8, in which a further span of the path becomes affected by a failure, **characterized by** comprising means for maintaining the re-routing action, performed because of the first failured span, should the persistency of the re-routing information be supported by the network elements of the ring network.

11. Network element according to claim 9, **characterized in that** said means for selecting one of the failured spans comprise means for considering the two spans adjacent to the switching nodes able to communicate with the termination nodes of path to be protected in the case where at least one further span of the path becomes affected by a failure.

12. Network element according to claim 9, said network element being a path termination node, **characterized by** comprising means for performing a Bridge&Switch action upon reception of two signalings comprising corresponding bridge requests with Bridge&Switch status code (BS) related to different spans.

13. Network element according to claim 9, said network element being a path non-termination node, **characterized by** comprising means for performing a pass-through action upon reception of at least one signaling comprising a bridge request with a Bridge&Switch status code (BS)

14. Network element according to claim 8 or 9, said network element being a path termination node, **characterized by** comprising means for performing a Bridge&Switch action upon reception of two signalings comprising corresponding bridge requests with Idle status code related to the same span.

15. Network element according to claim 9, said network element being a path non-termination node, **characterized by** comprising means for performing a pass-through action upon reception of at least one signaling comprising a bridge request with Idle status code.

16. Ring network comprising one or more network elements according to any of claims 8 to 15.

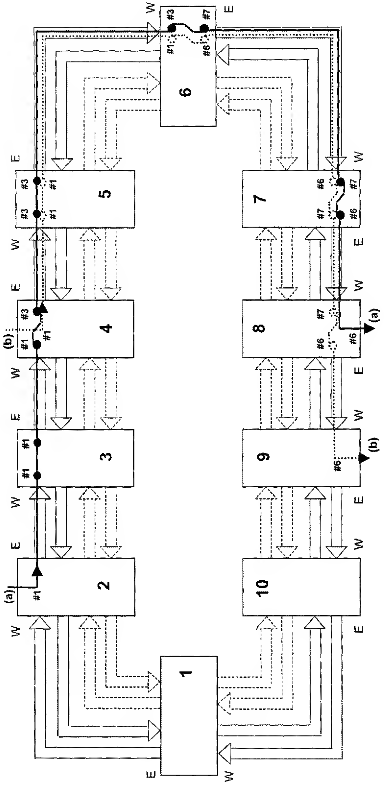


Fig. 1

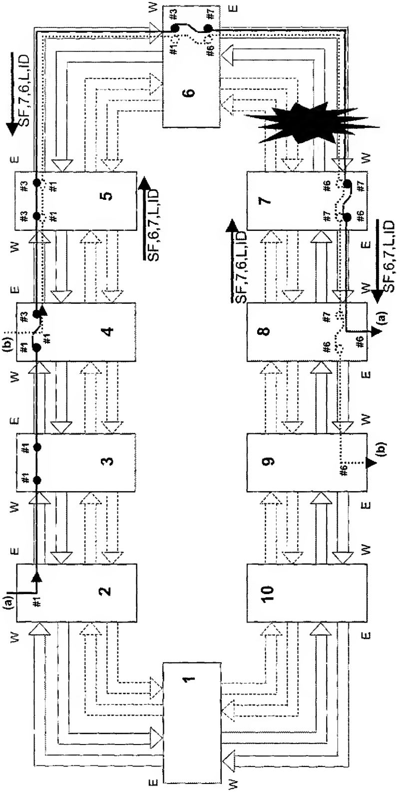


Fig. 2

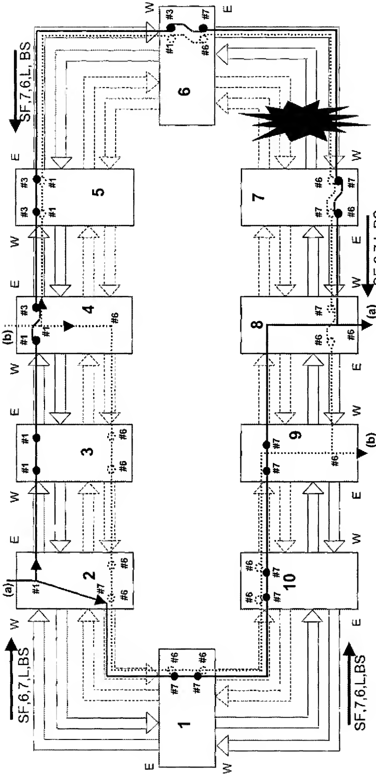


Fig. 3

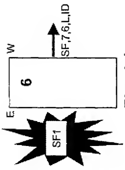


Fig. 4.1

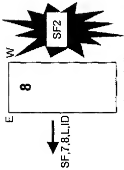


Fig. 4.2

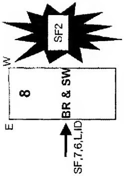


Fig. 4.3

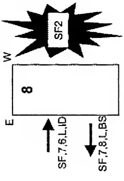


Fig. 4.4

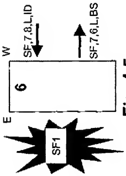


Fig. 4.5

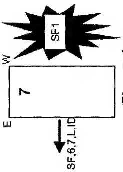


Fig. 5.1

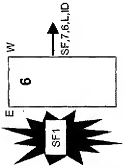


Fig. 5.2

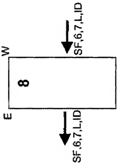


Fig. 5.3

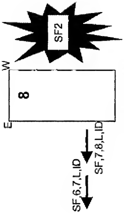


Fig. 5.4

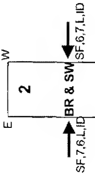


Fig. 5.5

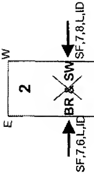


Fig. 5.6

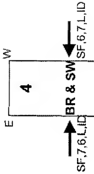


Fig. 5.7

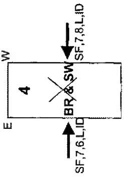


Fig. 5.8

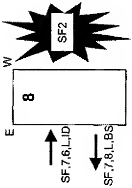


Fig. 5.9

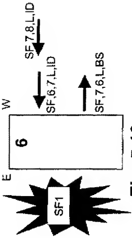
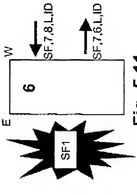


Fig. 5.10



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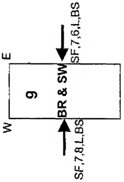

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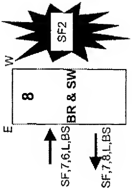

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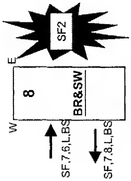

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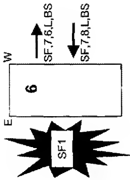

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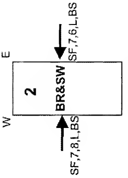

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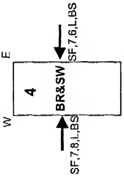

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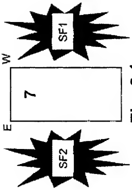

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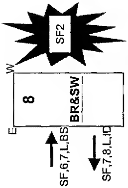

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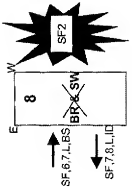

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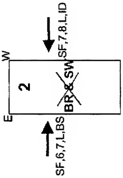

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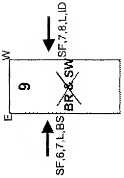

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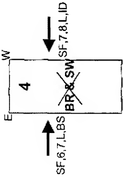

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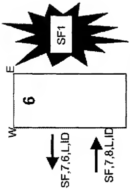

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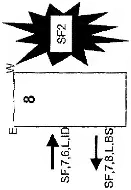

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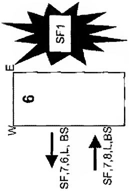

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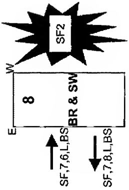

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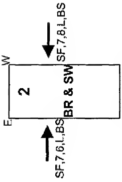

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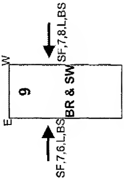

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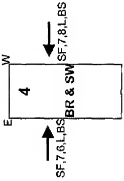

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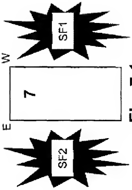

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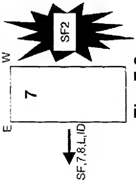

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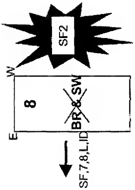

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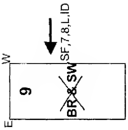

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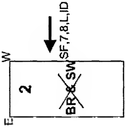

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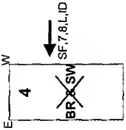

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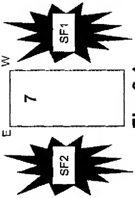
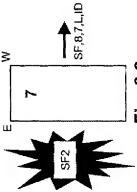


Fig. 8.1



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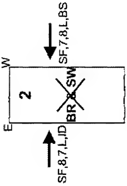

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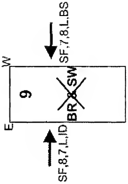

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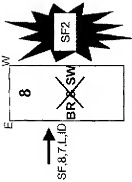

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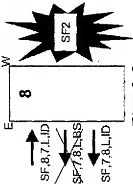

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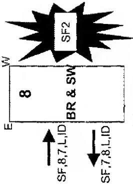

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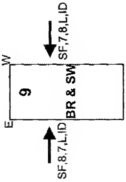

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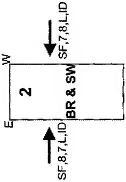

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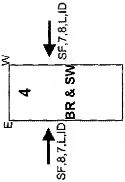

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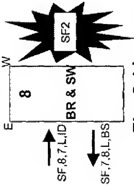

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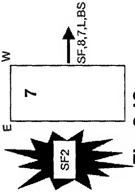

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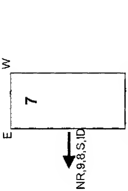

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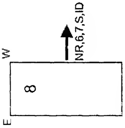

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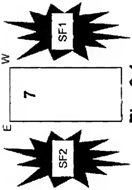
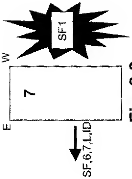


Fig. 9.1



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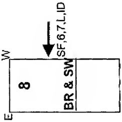

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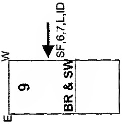

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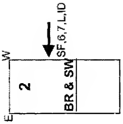

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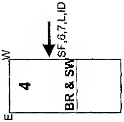

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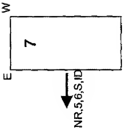

Fig. 9.7

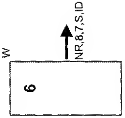

Fig. 9.8

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(71) Applicant: **Sony International (Europe) GmbH
10785 Berlin (DE)**

(72) Inventors:
- **Wang, Zhaocheng,
Sony International (Europe) GmbH
70327 Stuttgart (DE)**
- **Stirling-Gallacher, Richard, Sony International
70327 Stuttgart (DE)**

(74) Representative: **Rupp, Christian, Dipl.Phys. et al
Mitscherlich & Partner
Patent- und Rechtsanwälte
Sonnenstrasse 33
80331 München (DE)**

(54) Multicarrier system with adaptive bit-wise interleaving

(57) The present invention relates to a method for transmitting data streams of users via a transmission path in an OFDM system, whereby the data streams of respective users are transmitted in blocks, frequency hopping according to a predefined frequency hopping pattern for the respective transmission is performed, the block size for each user and within a hopping pattern can vary, and consecutive bits of the data stream to be transmitted are bit-wise interleaved, so that consecutive bits are transmitted in non-adjacent time slots and/or subcarriers within a block according to a predefined interleaving pattern. Thereby, the respective interleaving pattern is made adaptive to the respective frequency hopping pattern and/or the respective block size.

The present invention relates further to a transmitting station (1) for transmitting data streams of users and a receiving station (2) for receiving data streams of users for carrying out this method.

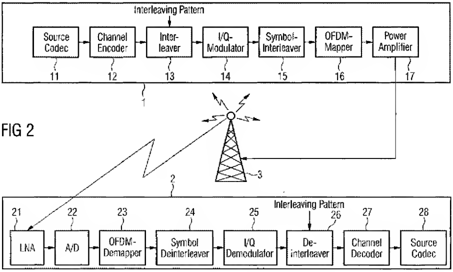

FIG 2

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Description

[0001] The present invention relates to a method for transmitting data in an orthogonal frequency division multiplex system (OFDM System). The present invention relates further to a transmitting station and a receiving station for carrying out this method.

[0002] The so-called orthogonal frequency division multiplex system (OFDM system) is widely used in broadcast systems like Digital Audio Broadcasting (DAB) and Digital Video Broadcasting (DVB) as e.g. described in EN 300 744 V1.2.1 of ETSI (European Telecommunication Standards Institute). This transmission system is also recommended for future wireless communication systems like BRAN (Broadband Radio Access Networks) and HIPERLAN (High Performance Radio Local Area Networks) as described in ETSI TS 101 475 V1.1.1 in order to provide high data rate services. Within these systems, the introduction of a bit-wise interleaver has increased the performance for high-level modulation schemes (e.g. 16QAM, 64QAM, Quadrature Amplitude Modulation), which are required for data transmission at a high-transfer rate.

[0003] A bit-wise interleaver interleaves consecutive and adjacent, respectively, bits of a data stream in a way, that adjacent bits of the data stream are transmitted in non-adjacent time slots and subcarriers, respectively. This has the advantage that associated transfer functions of respective consecutive bits (i.e. subcarrier and/or time slot number) are uncorrelated. In other words, particularly negative properties like e.g. deep fading of a specific transfer channel, do not take effect on consecutive bits, but rather only on single bits, e.g. of one transmitted symbol.

[0004] In wireless multi-user OFDM systems like e.g. BDMA systems (Band Division Multiple Access), for each user a predefined or fixed number of subcarriers and time slots can be assigned based on the required data rate. This assignment can change pseudo-randomly across the time/frequency-grid of an OFDM transmission path. This assignment is defined as one hopping pattern for one user, where at any one time slot some predefined or fixed subcarriers are allocated.

[0005] Figure 1 illustrates the transmission of data in an OFDM system with frequency hopping, whereby figure 1 shows a hopping pattern (assignment) for one user in a wireless multi-user OFDM system. Thereby, the time axis is divided into time slots of a predefined length and the frequency axis is divided into subcarriers of a predefined bandwidth.

[0006] As seen in figure 1, the data transmission for one user takes place in blocks, whereby each block has a length of a predefined number of time slots and a width of a predefined number of subcarriers. According to a hopping pattern, the (frequency) location, i.e. the frequencies occupied by a respective block within the transmitting path, of each block changes pseudo- randomly.

[0007] As shown in figure 1, the transmission of one user can also take place in more than one block within one period of time slots. This is illustrated in figure 1 as a hatched and a massive block, whereby both blocks belong to the data transmission of one user.

[0008] For each user, the respective corresponding hopping pattern can be repeated within any period of time, e.g. within one frame, one superframe or any other predefined fixed time period. In order to reduce the control burden, the hopping pattern for the respective user is assigned during a link initialisation and establishment phase and it does usually not change before the respective link (i.e. data transmission of one user) is released.

[0009] The block size, i.e. number of time slots and number of subcarriers, can be different for different users, it can also change from block to block (and between the different hopping steps, respectively) within a hopping pattern. These parameters are dependent of the required data rate and the resource management of the transmitting station (base station).

[0010] However, introducing a bit-wise interleaver in such an OFDM system, which performs frequency hopping as described in relation to figure 1, has the disadvantage, that, particularly at a relative small block size, the associated channel transfer functions can not be kept uncorrelated, since the time slot and/or subcarrier distance between the consecutive bits can not been made large enough.

[0011] Thus, due to the limited number of subcarriers at one specific time slot and the limited block size, respectively, it is difficult to implement the bit-wise interleaver according to the prior art in an OFDM frequency hopping system.

[0012] From WO 00/35102 an interleaving/de-interleaving device and a method for a communication system are known. A device for sequentially storing input bit symbols of a given interleaver size in a memory at an address and reading the stored bit symbols from the memory is provided. This known implementation method for an interleaver can be used for example based on CDMA-2000 specification or for other IMT-2000 communication systems. However, it cannot find application for the design of interleaver patterns for multi-user OFDM hopping systems.

[0013] From US 6,125,150 a transmission system using code design for transmission with periodic interleaving is known. Thereby an OFDM transmission system provides a high level of performance on a variety of frequency selective channels by using a code having the characteristics of maximum PPD and maximum PECL. The codes are designed to allow high SNR sub-channels to carry their full potential of information which is then used to compensate for information lost on low SNR sub-channels. According to this known technology error control coding, modulation and interleaver are combined together to obtain better distance characteristics, where some subcarriers may carry more information and another sub-carriers may carry less information

depending on the channel transfer functions.

[0014] It is therefore the object of the present invention to provide a technique for transmitting data streams in an orthogonal frequency division multiplex system (OFDM system), whereby the performance of interleaving and therefore the performance of the transmission is improved.

[0015] The above object is achieved by a method of transmitting data streams of users via a transmission path in a OFDM system according to claim 1.

[0016] This object is further achieved by a transmitting station and a receiving station for carrying out this method according to claims 7 and 8.

[0017] The method for transmitting data streams of users via a transmission path in a OFDM system according to the present invention performs a data transmission. The time axis of the transmission path is divided into time slots The frequency axis of the transmission path is divided into subcarriers. The resource of the transmission path is used by a plurality of users. The data streams of the respective users are transmitted in blocks with a block size of a predefined length of time slots and a predefined number of subcarriers. Frequency hopping according to a predefined frequency hopping pattern for the respective transmission is performed. The frequency hopping pattern for a respective transmission can differ between different users and it also can differ between different times for the same user.

[0018] Further, the frequencies occupied by a respective block within the transmission path vary according to the frequency hopping pattern. The block size for each user within a hopping pattern can also vary. Consecutive bits of the data stream to be transmitted can be bit-wise interleaved such that consecutive bits are transmitted in non-adjacent time slots and/or subcarriers according to a predefined interleaving pattern.

[0019] According to the present invention, the respective interleaving pattern is thereby made adaptive (and can be a function of) to the respective frequency hopping pattern and/or the respective block size.

[0020] The transmitting station according to the present invention for transmitting data streams of users comprises an interleaving means for bit-wise interleaving consecutive bits of data streams according to a predefined interleaving pattern, whereby the interleaving means uses an interleaving pattern, which is made adaptive to the respective frequency hopping pattern and/or the respective block size.

[0021] The receiving station for receiving data streams of users, which are transmitted according to the above-mentioned method according to the present invention comprises an deinterleaving means for deinterleaving the received data streams into the original bit sequence according to a predefined interleaving pattern, whereby the deinterleaving means uses an interleaving pattern, which is made adaptive to the respective frequency hopping pattern and/or the respective block size.

[0022] The present invention has the advantage that the performance of high level modulation schemes, like 16QAM, 64QAM or higher, can be improved, since the bit-wise interleaving is made adaptive to the respective data transmission, i.e. the respective hopping pattern and/or block size of the respective transmission. Parasitic characteristics of respective channels are minimised, since e.g. deep fading ideally take only effect on single bits e.g. of one transmitted symbol.

[0023] Thereby, consecutive bits are transmitted within the same block, when the transmitted blocks are large enough, that means, when a block size allows to transmit consecutive bits in the same block so that the associated channel transfer functions keep uncorrelated.

[0024] Consecutive bits can also be transmitted in different blocks according to the interleaving pattern. Advantageously, consecutive bits are transmitted in different blocks, when the block size is very small, so that the associated channel transfer functions for consecutive bits can be kept uncorrelated.

[0025] Further advantageously, the interleaving pattern is made adaptive to the number of time slots of the respective block and/or the interleaving pattern is made adaptive to the number of subcarriers of the respective block.

[0026] In the following description a preferred embodiment of the present invention is explained in more detail in relation to the enclosed drawings, in which

Figure 1 shows an example of data transmission in an OFDM system with frequency hopping,

Figure 2 shows a block diagram of a wireless OFDM system according to the present invention,

Figure 3 shows a diagram of 16QAM and 64QAM mappings and the corresponding bit pattern,

Figure 4 shows one example of the mapping of one symbol into the time-frequency grid of OFDM, and

Figure 5 shows another example of the mapping of one symbol into the time-frequency grid of OFDM.

[0027] Figure 2 shows a schematic diagram of a wireless OFDM system according to the present invention, whereby a block diagram of a transmitting station 1 and a block diagram of a receiving station 2 are depicted.

[0028] The transmitting station 1 according to the present invention comprises a source codec 11 for coding the signals which have to be transmitted (e.g. audio or video signal) into a data stream of a digital signal, and a channel encoder 12 for encoding a data stream e.g. into a frame structure, adding redundancy bits, etc.

[0029] Then, the data stream is adaptively bit-wise interleaved by the interleaver 13 according to the present invention. The pattern for bit-wise interleaving the data stream is thereby made adaptive to predefined param-

eters of the respective transmission like frequency hopping pattern and block size. In other words, the pattern is a function of said parameters. The adaptive interleaving according to the present invention is described later in more detail with reference to Figs. 4 and 5.

[0030] After interleaving the data stream is modulated into symbols, e.g. according to the known I/Q modulation (In-phase/Quadrature modulation), by an I/Q modulator 14 and map into a time/frequency-grid by an OFDM mapper 16. Optionally, the data stream can be symbol-wise interleaved by a symbol interleaver 15 as known from the prior art in order to further improve the transmission performance.

[0031] The OFDM mapper 16 maps the modulated data stream into the time/frequency-grid according to the OFDM transmission system. Further, the OFDM mapper 16 determines the block size and the used frequency hopping pattern, both dependent e.g. upon a given users data rate and resource management in the transmitting station 1.

[0032] Then, the mapped data stream is than amplified by a power amplifier 17 and transmitted via a radio tower 3 over an air-interface to one or plurality of receiving stations.

[0033] The receiving and demodulating of data by the receiving station 2 is carried out in the inverse sequence.

[0034] Thereby, the signal transmitted by the radio tower 3 is received by an antenna comprising a low noise amplifier 21 (LNA). The received signal (comprising the data stream) is analogue/digital converted by an A/D converter 22.

[0035] Complementary to the OFDM mapper 16 of the transmitting station 1, the received signal is demapped by an OFDM demapper 23. The signal is thereby demapped according to the same pattern for mapping the data stream by the OFDM mapper 16 in order to reconstruct the original data stream.

[0036] If the signal is symbol-wise interleaved by the transmitting station 1, the signal has to be symbol-wise deinterleaved by a symbol deinterleaver 24.

[0037] After I/Q demodulation of the demapped data stream by the I/Q demodulator 25, the data stream is bit-wise deinterleaved by the deinterleaver 26. Thereby, the pattern for deinterleaving the data stream is made adaptive to the hopping pattern for mapping/demapping the signal; the pattern for bit-wise deinterleaving is similar to the interleaving pattern used by the transmitter 1 in order to get the original data stream.

[0038] Channel decoding and source decoding is performed by a channel decoder 27 and source decoder 28 similar to the source coding and channel coding of the transmitting station 1.

[0039] Figure 3 shows the principles of QAM (Quadrature Amplitude Modulation) based on the example of 16QAM and 64QAM.

[0040] For QAM the information is transmitted with an in-phase and a quadrature component Q. Thus, the carrier comprises respective to the information, which are transmitted, an in-phase (I) and an quadrature (Q) component. Thereby, dependent on the modulation scheme (e.g. 16QAM or 64QAM), one transmitted symbol carries 4 bits at 16QAM (respectively 2 bits for I- and Q-channel) and 6 bit at 64QAM (respectively 3 bits for I- and Q-channel) pursuant to the scheme as shown in the respective coordinate system of 16QAM and 64QAM; the bit order is termed by I1, Q1, I2, Q2 and I1, Q1, I2, Q2, I3, Q3, respectively.

[0041] Thereby, the high priority bits are I1 and Q1. For 16QAM, the low priority bits are I2 and Q2, for 64QAM, the low priority bits are I3 and Q3. At the example of 64QAM (encircled symbol 000011) it is illustrated, that the high priority bits are less susceptible against interferences than the low priority bits. If, e.g., this symbol is interfered, it could be decoded wrongly as an adjacent symbol, e.g. as 000010, 000111, 001011 or 000001. It is seen, that the high priority bits are always the same, namely 00. Thus, the high priority bis are more protected against interferences than the low priority bits.

[0042] Figure 4 shows one example of a pattern for mapping a data stream into a time/frequency-grid by the OFDM mapper 16 shown in figure 2.

[0043] In this example, the hopping pattern for one user is shown. Thereby, each use is assigned two blocks (shown as hatched and solid blocks). Since the respective blocks are very small, i.e. low number of subcarriers in this example, consecutive bits of one symbol, e.g. I1, Q1, I2, Q2 are transmitted in different blocks, interleaved according to a bit-wise interleaving pattern A.

[0044] Figure 5 shows a different hopping pattern for mapping a data stream into the time/frequency-grid.

[0045] Thereby, the block size differs between the single hopping steps. E.g. in the first block and the third block are transmitted two consecutive bits (respectively I1, Q1 and I2, Q2), since the block size is large enough. In this case, bit-wise the interleaving happens according to an interleaving pattern B.

[0046] Thus, the design rule of a bit-wise interleaver 13 as shown in figure 1 is as follows:

- Adjacent coded bits from channel encoder are mapped onto non-adjacent subcarriers or non-adjacent time slots. The frequency separation (distance) of the chosen subcarriers or the time separation of the chosen time slot has to be far enough in order to keep the associated channel transfer functions uncorrelated.

- Adjacent coded bits from channel encoder are mapped alternatively on high or low priority bits. By this way, long runs of low reliability bits are avoided.

- The coded bits are placed at all available subcarriers and time slots on OFDM time/frequency-grid within the depth, i.e. the time/frequency/block dis-

tance between consecutive bits, of the interleaver are used.

- The bit-wise interleaver pattern is made adaptive to the hopping pattern in order to achieve better system performance.

[0047] The present invention has the advantage, that the performance of high level modulation schemes, like 16QAM, 64QAM or higher, can be improved, since the bit-wise interleaving is made adaptive to the respective data transmission, i.e. the respective hopping pattern and/or block size of the respective transmission. Parasitic characteristics of respective channels are minimised, since e.g. deep fading ideally take only effect on single bits e.g. of one transmitted symbol.

[0048] According to invention therefore a new design rule is proposed for a bit-wise interleaver for multi-user OFDM hopping systems. Instead of placing data bits belonging to one I/Q symbol or adjacent symbols on different sub-carriers at the same timeslot, data bits belonging to one I/Q symbol or adjacent symbols can be placed at different timeslots or at different blocks within the bit-wise interleaver.

[0049] Furthermore, in multi-user OFDM hopping systems, where each user can be assigned different hopping patterns (depending upon a given user's data rate and resource management in the base station) at different times, it is proposed that the practical bit-wise interleaver pattern to be used for each user is variable and depends upon its assigned hopping pattern. In this way the optimal performance can be obtained.

[0050] Each sub-carrier thereby carries the same size of information. By using a bit-wise interleaver, the bits belonging to one symbol are interleaved. Therefore, the good performance can be achieved for error control coding. Therefore, the use of a bit-wise interleaver can be enabled for multi-user OFDM hopping systems.

Claims

1. Method for transmitting data streams of users via a transmission path in an OFDM system, whereby
the time axis of the transmission path is divided into time slots,
the frequency axis of the transmission path is divided into subcarriers,
the transmission path is used by a plurality of users,
the data streams of the respective users are transmitted in blocks with a block size of a predefined length of time slots and a predefined number of subcarriers,
frequency hopping according to a predefined frequency hopping pattern for the respective transmission is performed, whereby the frequency hopping pattern for respective transmission can differ between different users and differ between different times for the same user,
the frequencies occupied by a respective block within the transmission path vary according to the frequency hopping pattern,
the block size for each user and within a hopping pattern can vary, and
consecutive bits of the data stream to be transmitted are bit-wise interleaved, so that consecutive bits are transmitted in non-adjacent time slots and/or subcarriers according to a predefined interleaving pattern,
characterised in
that the respective interleaving pattern is made adaptive to the respective frequency hopping pattern and/or the respective block size.

2. Method according to claim 1,
characterised in
that consecutive bits are transmitted within the same block, in case the block size is large.

3. Method according to claim 1,
characterised in
that consecutive bits are transmitted in different blocks according to the interleaving pattern.

4. Method according to claim 3,
characterised in
that consecutive bits are transmitted in different blocks, in case the block size is small.

5. Method according to one of the claims 1 to 4,
characterised in
that the interleaving pattern is made adaptive to the number of time slots of the respective block.

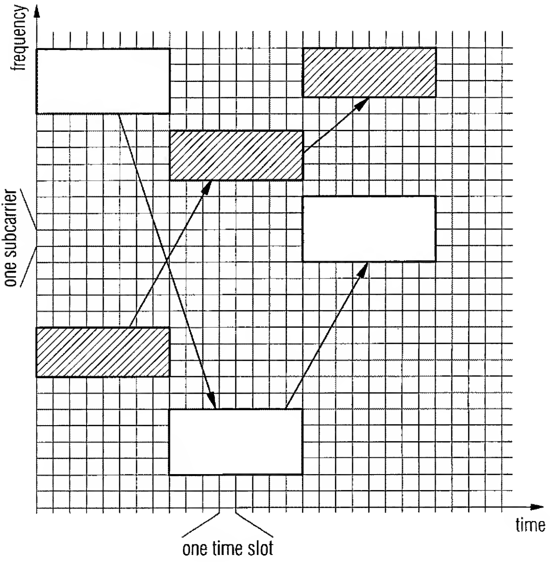
6. Method according to one of the claims 1 to 5,
characterised in
that interleaving pattern is made adaptive to the number of subcarriers of the respective block.

7. Transmitting station (1) for transmitting data streams of users by using a method according to anyone of the claims 1 to 6,
characterised by
an interleaving means (13) for bit-wise interleaving consecutive bits of data streams according to a predefined interleaving pattern, whereby the interleaving means (13) uses an interleaving pattern, which is made adaptive to the respective frequency hopping pattern and/or the respective block size.

8. Receiving station (2) for receiving data streams of users, which are transmitted using a method for transmitting data streams according to anyone of the claims 1 to 6,
characterised by
an deinterleaving means for deinterleaving the re-

ceived data streams into the original bit sequence according to a predefined interleaving pattern, whereby the deinterleaving means uses an interleaving pattern, which is made adaptive to the respective frequency hopping pattern and/or the respective block size.

FIG 1



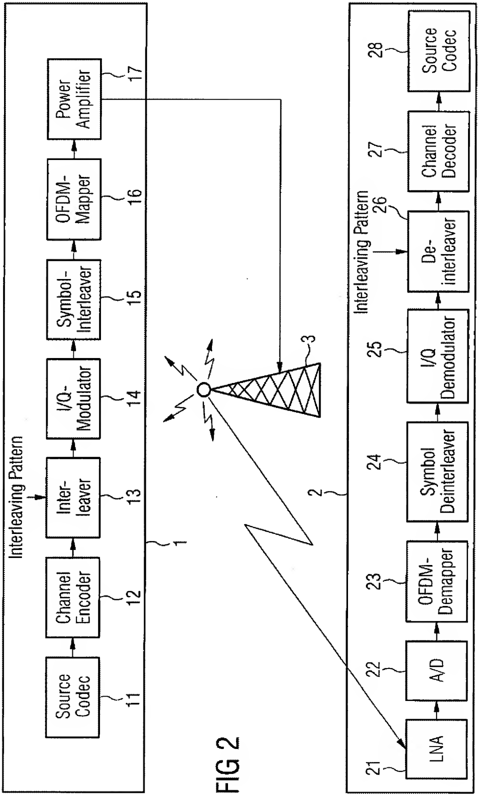
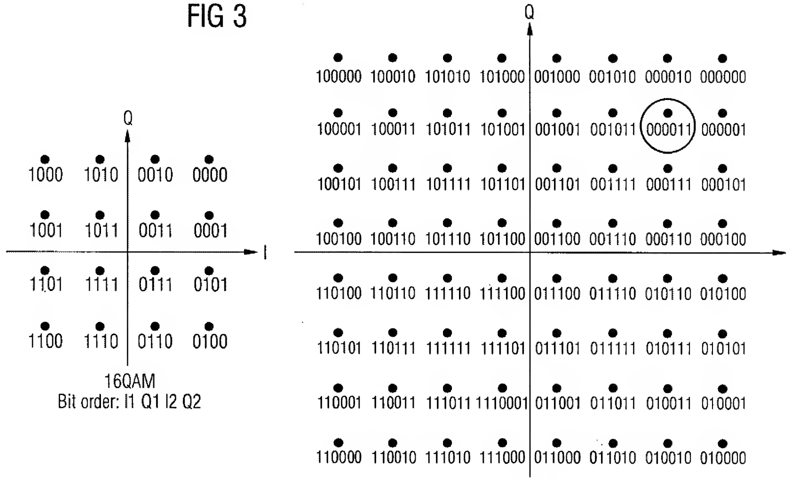

Interleaving Pattern
Source Codec
11
Channel Encoder
12
Inter-leaver
13
I/Q-Modulator
14
Symbol-Interleaver
15
OFDM-Mapper
16
Power Amplifier
17
1
3
2
LNA
21
A/D
22
OFDM-Demapper
23
Symbol Deinterleaver
24
I/Q Demodulator
25
Interleaving Pattern
De-interleaver
26
Channel Decoder
27
Source Codec
28

FIG 2

FIG 3



16QAM
Bit order: I1 Q1 I2 Q2

64QAM
Bit order: I1 Q1 I2 Q2 I3 Q3

FIG 4
Interleaving Pattern A

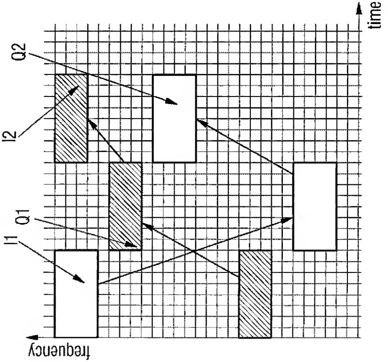
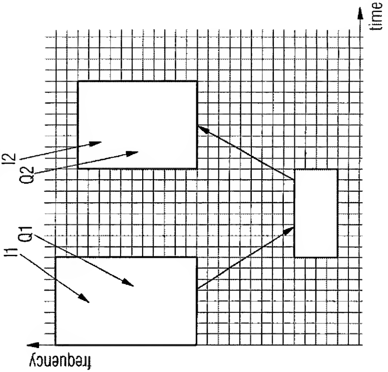


FIG 5
Interleaving Pattern B



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EUROPEAN SEARCH REPORT

Application Number
EP 01 11 4041

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	17 October 2001	Papantoniou, A

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X : particularly relevant if taken alone
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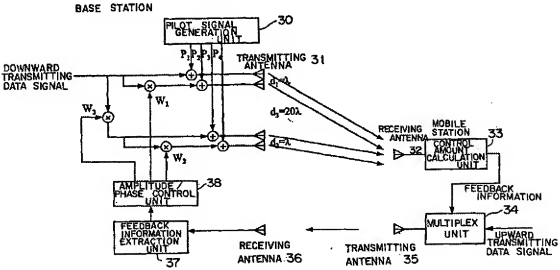
(71) Applicant: **FUJITSU LIMITED**
Kawasaki-shi, Kanagawa 211-8588 (JP)

(72) Inventor: **TANAKA, Yoshinori, Fujitsu Limited**
Kawasaki-shi, Kanagawa 211-8588 (JP)

(74) Representative: **HOFFMANN - EITLE**
Patent- und Rechtsanwälte
Arabellastrasse 4
81925 München (DE)

(54) **TRANSMISSION DIVERSITY COMMUNICATION DEVICE**

(57) The plurality of antennas of a base station used for transmitting diversity are divided into groups. Each antenna is located so that signals transmitted from antennas in the same group have a high fading correlation. Each antenna group is spaced so that a fading correlation between the groups may become low. Since signals transmitted from an antennas in the same group have high fading correlation, such signals suffer little from fading fluctuations and a low control speed is acceptable. However, control between the groups must be exercised at a high speed. Therefore, a mobile station that receives the signals of the base station feeds back feedback information for controlling fading fluctuations between the groups and information within a group to the base station at a high transfer rate and at a low transfer rate, respectively.



F I G. 4

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Description

Technical field

[0001] The present invention relates to a transmitting diversity communications apparatus.

Background Art

[0002] Transmitting diversity in W-CDMA, which is the third-generation mobile communications system, adopts a method using two transmitting antennas.

[0003] Fig. 1 shows an example configuration of a transmitting diversity system using two transmitting antennas.

[0004] Mutually orthogonal pilot patterns P_1 and P_2 are transmitted from two transmitting antennas 1 and 2, respectively, as pilot signals, and channel impulse response vectors $\underline{h}_1$ and $\underline{h}_2$ from each antenna of a base station up to the receiving antenna of a mobile station are estimated by correlating each known pilot pattern to an incoming pilot on the receiving side of the mobile station.

[0005] A control amount calculation unit 10 calculates and quantizes the amplitude/phase control vector (weight vector) $\underline{w}=[w_1, w_2]$ of each transmitting antenna of the base station that maximizes power P expressed by the following equation (1) using these channel estimation values. Then, a multiplex unit 11 multiplexes the quantized weight vectors with an uplink channel signal as feedback information and transmits the signal to the base station. However, since there is no need to transmit both values w_1 and w_2, it is acceptable to transmit only value w_2 obtained by assigning w_1=1.

$$P = \underline{w}^H H^H H \underline{w} \qquad (1)$$

$$H = [\underline{h}_1, \underline{h}_2] \qquad (2)$$

[0006] In equation (2), $\underline{h}_1$ and $\underline{h}_2$ are the channel impulse response vectors from the transmitting antennas 1 and 2, respectively, and the superscript H on H^H and w^H indicates the Hermitian conjugation of H and w, respectively. If an impulse response length is assumed to be L, the channel impulse response vector is expressed as follows.

$$\underline{h}_i = [h_{i1}, h_{i2}, ..., h_{iL}] \qquad (3)$$

[0007] Therefore, in the case of two transmitting antennas, equation (1) is calculated based on the following algebraic calculation.

$$H = \begin{bmatrix} h_{11} & h_{21} \\ h_{12} & h_{22} \\ \vdots & \vdots \end{bmatrix} \quad , \quad \underline{w} = [w_1, w_2]^T \quad ,therefore \quad Hw = \begin{bmatrix} h_{11}w_1 + h_{21}w_2 \\ h_{12}w_1 + h_{21}w_2 \\ \vdots \end{bmatrix}$$

[0008] At the time of handover, weight vector $\underline{w}$ that maximizes the following equation is calculated instead of equation (1).

$$P = \underline{w}^H (H^H{}_1 H_1 + H^H{}_2 H_2 + ...) w \qquad (4)$$

[0009] In equation (4), H_k is a channel impulse response signal from the k-th base station.

[0010] Then, the feedback information extraction unit 12 on the transmitting side extracts w_2 (in this case, w_1=1 is assumed) transmitted from a mobile station, from an incoming signal and an amplitude/phase control unit 13 multiplies a data signal to be transmitted from the transmitting antenna 2 by W_2. In this way, the degradation of both the amplitude and phase of signals received from the transmitting antennas 1 and 2 that are received on the receiving side are corrected in advance and are transmitted from the transmitting side.

[0011] In W-CDMA, two methods are stipulated: mode 1 for quantizing weight coefficient w_2 into one bit and mode 2 for quantizing w_2 into four bits. In mode 1, since control is exercised by transmitting one bit of feedback information for each slot, control speed is high. However, since quantization is rough, accurate control is impossible. In mode 2, since control is exercised by transmitting four bits of information, more accurate control is possible. However, in mode 2, since only one bit can be transmitted for each slot and feedback information of one word is transmitted for every four slots, control cannot track fading in the case of a high fading frequency, and amplitude/phase characteristics degrade. As described above, if the signal transfer rate of an uplink channel from a mobile station to a transmitting station, for transmitting feedback information is restricted, control accuracy and fading track speed have an inverse relationship.

[0012] The Release-99 specification of W-CDMA standard does not take into consideration a case where more than two transmitting antennas are used so as to avoid the degradation of uplink channel transmission efficiency due to feedback information transmission. However, if the increase of feedback information or the degradation of update speed is allowed, the number of antennas can also be increased to three or more. In particular, currently a case where four transmitting antennas are used is being extensively researched and developed.

[0013] If a closed-loop transmitting diversity system is applied to the radio base station of a cellular mobile communications system, a signal from each transmitting antenna independently suffers from fading, and ideally the same phase combination is performed at the antenna position of the mobile station. Therefore, a diversity gain corresponding to the number of transmitting antennas can be obtained and the gain can also be improved by the combination. Accordingly, the receiving characteristic is improved and the number of users accommodated in one cell can also be increased. "Ideally" means a case where there is neither transmission error of feedback information, control delay, channel response estimation error nor quantization error of a control amount. In reality, the characteristic degrades due to these factors compared with that of the ideal case.

[0014] In order to obtain a diversity gain corresponding to the number of antennas, antenna spacings (the distances between antennas) must be wide so that fading correlation may become sufficiently low. Generally, in order to suppress fading correlation to a sufficiently low level in the radio base station of a cellular mobile communications system, antenna spacings must be approximately 20 wavelengths. Since one wavelength is approximately 15cm in a 2GHz band, antennas must be installed approximately 3 meters apart. Therefore, if the number of transmitting antennas increases, an area needed to install antennas becomes wide and it becomes difficult to install antennas on the roof of a building and the like, which is a problem. Diversity gain is saturated as the number of transmitting antennas increases. Therefore, when the number of transmitting antennas reaches a specific value, the diversity gain cannot be improved any further even if the number of transmitting antennas is further increased.

[0015] When the number of transmitting antennas is increased, an amount of information to be fed back increases since feedback information must be transmitted to each antenna. Therefore, in that case, the transmission efficiency of an uplink channel degrades due to feedback information transmission or the control of transmitting diversity cannot track high-speed fading. As a result, the characteristic degrades, which is another problem.

Disclosure of Invention

[0016] An object of the present invention is to provide a transmitting diversity communications apparatus for suppressing the increase of uplink feedback information if the number of transmitting antennas is increased, suppressing the degradation of a characteristic in the case of a high fading frequency and requiring a small antenna installation space in the base-station.

[0017] The transmitting diversity communications apparatus of the present invention includes a transmitting diversity base station for controlling transmitting signals, according to information from a mobile station. The transmitting diversity communications apparatus comprises an antenna unit composed of a plurality of antenna groups, each consisting of a plurality of antennas, located close to each other so that the fading correlation between the antennas in the same group is high and groups are located apart from one another so that the fading correlation between the groups is low, and a control unit receiving both the first control information about intra-group antenna control with a low transfer rate that is transmitted from a mobile station and the second control information about inter-group antenna control and controlling the phase of a signal transmitted by the antenna unit.

[0018] According to the present invention, if signal control is applied to a closed-loop transmitting diversity system by the same method as in the conventional case where two transmitting antennas are used, by increasing the number of transmitting antennas, the tracking of fading fluctuations and transmitting-signal control performance can be prevented from degrading due to the increase of an amount of information to be transmitted from a mobile station to a base station.

[0019] In particular, according to the present invention, since the antenna unit of a base station is composed of a plurality of antenna groups each consisting of a plurality of antennas, and each intra-group antenna and each antenna group is set so that fading correlation is high within a group and so that fading correlation is low between groups,

respectively, only transmitting-signal control information between groups must be transmitted at a high speed from a mobile station to a base station and transmitting-signal control information within a group can be relatively slow. Therefore, transmitting diversity performance can be improved by effectively utilizing the limited transfer rate of an upward line from a mobile station to the base station.

Brief Description of Drawings

[0020]

Fig. 1 shows an example configuration of a transmitting diversity system using two transmitting antennas.
Fig. 2 shows the system configuration of the present invention.
Fig. 3 shows an example configuration of transmitting antennas of a base station according to the preferred embodiment of the present invention.
Fig. 4 shows the configuration of one preferred embodiment of the present invention.
Fig. 5 shows an example of a downlink pilot signal pattern in the preferred embodiment.
Fig. 6 shows both an example configuration of a base station transmitting antennas and antenna control information according to the preferred embodiment.
Fig. 7 shows an envelope correlation coefficient obtained when the angle dispersion $\Delta\phi$ of an input signal observed at a base station in a macro-cell environment is approximately 3.
Fig. 8 shows an example of the transmission format of feedback information in the preferred embodiment (No. 1).
Fig. 9 shows an example of the transmission format of feedback information in the preferred embodiment (No. 2).
Fig. 10 shows an example of the transmission format of feedback information in the preferred embodiment (No. 3).
Fig. 11 shows an example of the transmission format of feedback information in the preferred embodiment (No. 4).
Fig. 12 shows an example configuration of a mobile station for transmitting feedback information to a base station according to the formats shown in Figs. 8 through 11.
Fig. 13 shows an example configuration of a base station in the second preferred embodiment of the present invention.
Fig. 14 shows an antenna phase difference control method within a group in the second preferred embodiment.
Fig. 15 shows the configuration of the third preferred embodiment of the present invention.

Best Mode for Carrying Out the Invention

[0021] The present invention relates to a closed-loop transmitting diversity method according to which the radio base station of a cellular mobile communications system is provided with a plurality of antennaslements, both different amplitude and phase control are exercised over the same transmitting data, according to feedback information from a mobile station and a plurality of pieces of data are transmitted using different antennas. On the mobile station side, the amplitude/phase control amounts are determined using a downward pilot signal; feedback information indicating the amplitude/phase control amounts are multiplexed with an uplink channel signal; and the data is transmitted to the base station.

[0022] Fig. 2 shows the system configuration of the present invention.

[0023] The pilot signal generation unit 20 of a base station generates N mutually orthogonal pilot signals $P_1(t)$, $P_2(t)$, ..., $P_N(t)$ and the pilot signals are transmitted using different antennas. N is the number of transmitting antennas. The following relationship is established between these pilot signals.

$$\int P_i(t)P_j(t)dt = 0 \quad (i \neq j)$$

[0024] Each pilot signal suffers from both amplitude and phase fluctuations due to fading, and a signal obtained by combining these pilot signals is transmitted to the receiving antenna 22 of a mobile station. The receiver of the mobile station estimates the channel impulse response vectors h_1, h_2, ..., h_N of each pilot signal by calculating the correlation between the incoming pilot signal and each of $P_1(t)$, $P_2(t)$, ..., P_N (t).

[0025] A control amount calculation unit 23 calculates and quantizes the amplitude/phase control vector (weight vector) $\underline{w}=[w_1, w_2, ..., w_N]^T$ of each transmitting antenna of the base station that maximizes power P expressed by equation (5)(the same as equation (1)) using these channel impulse response vectors. A multiplex unit 24 multiplexes the quantized vector with an upward channel signal as feedback information and transmits the signal to the base station side. However, in this case it is acceptable to transmit values w_2, w_3, ..., w_N obtained by assigning w_1=1.

$$P = \underline{w}^H H^H H \underline{w} \quad (5)$$

$$H = [\underline{h}_1, \underline{h}_2, ..., \underline{h}_N] \quad (6)$$

[0026] In equation (6), $\underline{h}_1$ is a channel impulse response vector from transmitting antenna i. If an impulse response length is assumed to be L, $\underline{h}_1$ is expressed as follows.

$$\underline{h}_1 = [h_{i1}, h_{i2}, ..., h_{iL}]^T \quad (7)$$

[0027] At the time of hand-over, weight vector w that maximizes the following equation is calculated instead of equation (5).

$$P = \underline{w}^H (H_1^H H_1 + H_2^H H_2 + ...) \underline{w} \quad (8)$$

[0028] In equation (8), H_k is a channel impulse response signal from the k-th base station, and is the same as H_k in equation (4).

[0029] The multiplex unit 24 of the mobile station multiplexes the weight vector obtained in this way with an upward transmitting data signal and the vector is transmitted to the receiving antenna of the base station. In the base station, a feedback information extraction unit 25 extracts the feedback information received by a receiving antenna, and an amplitude/phase control unit 26 controls both the amplitude and phase transmitted from each transmitting antenna using a weight vector included in the feedback information. When the base station transmits a signal, both the amplitude and phase of which have been controlled from a transmitting antenna 21, the mobile station receives the signal as if the fluctuations due to just fading of both the amplitude and phase were compensated for. Therefore, optimal reception is possible. Since fading changes as time elapses, both the generation and transmission of feedback information must happen in real time. However, since both the transmission format and transfer rate of an uplink data signal from a mobile station to a base station is predetermined, it takes too much time to transmit a lot of information. Therefore, the control cannot track the fading fluctuations. In order to track the fading fluctuations, the transmission rate of feedback information must be high. However, since the transmission rate of an uplink control channel is limited, if a plurality of pieces of new information are sequentially transmitted in a short cycle in order to control transmitting diversity at a high speed, an amount of information included in one time transmission becomes small (quantization becomes rough), and highly accurate control becomes impossible.

[0030] In the preferred embodiment of the present invention, each coefficient value in a weight vector is calculated and fed back in a different cycle instead of calculating and feeding back a signal transmitted from each antenna in the same cycle.

[0031] The details are described below.

[0032] Fig. 3 shows an example configuration of the transmitting antennas of a base station according to the preferred embodiment of the present invention.

[0033] As shown in Fig. 3, in a base station, transmitting antennas compose a plurality of groups, each consisting of a plurality of antennas. Transmitting antennas in the same group are located close to one another so that the fading correlation between the antennas is high and groups are installed apart from one another so that the fading correlation between the groups is low. Fading correlation is a numeric value indicating how similarly two signals transmitted from different antennas fade when the signals are received on a receiving side. Doppler effect and the like cause fading by reflection on buildings and mobile objects. Therefore, if a plurality of antennas transmitting signals are located close to one another, it follows that a mobile station receives the respective signals through similar routes. Accordingly, the signals suffer from similar fading. In such a case, it is said that the fading correlation between the signals is high. If a plurality of antenna transmitting signals are located apart from one another, it follows that the respective signals take different routes to a mobile station receives the signals. Therefore, the signals fade differently and then are received by the mobile station. In such a case, it is said that the fading correlation between the signals is low.

[0034] In a mobile station, an antenna control amount between groups is calculated in a shorter cycle than that of the antenna control amount within a group, and is transmitted to a base station side as feedback information. Signals from base-station transmitting antennas in the same group have a high fading correlation; the signals suffer from almost the same fading, but the signals each have a phase difference depending on the angle at which the signals reach the receiving antenna of the mobile station. Therefore, each channel response estimation value estimated using the signals

from the plurality of base-station transmitting antennas in the same group has a phase difference that depends on the angle of the mobile station against the base station. Although these values change as the mobile station travels, the values change slowly compared with fading fluctuations. One antenna in each group is designated as a reference antenna, and each of the control amounts of antennas other than the reference antenna in the relevant group is normalized by the control amount of this reference antenna (each relative value calculated using the control amount of this reference antenna as a reference is used). This normalized antenna control amount in the group changes slowly as the mobile station travels. Therefore, the control cycle can be made relatively long.

[0035] However, since respective signals from base-station transmitting antennas belonging to different groups have a low fading correlation, the signals fade differently and independently by the time they reach the receiving antenna of the mobile station. Therefore, respective channel response estimation values (channel impulse response vector) estimated using respective signals from respective reference values belonging to different groups change quickly due to respective independent fading fluctuations. An antenna control amount obtained by normalizing the reference antenna control amount of one specific group by the reference antenna control amount of another group is defined as an inter-group antenna control amount. Since each inter-group antenna control amount changes quickly due to each independent fading fluctuation, in order to accurately control antennas, the control must be exercised in a short cycle.

[0036] The mobile station must recognize which signal comes from which group. However, it is sufficient to relate each antenna to each pilot signal transmitted from the antenna in advance. Since pilots are mutually orthogonal to one another, a receiving side can accurately recognize from which antenna the signal is transmitted by checking the pilot signal.

[0037] Both the inter-group antenna control amount $F_{1,m}$ and intra-group antenna control amount $G_{m,k}$ shown in Fig. 3 are calculated as follows. In the description given above, N, M and K=N/M are the total number of antennas, the number of antenna groups and the number of antennas in each group, respectively. * represents complex conjugation.

Overall reference antenna: Antenna #1

Intra-group reference antenna: Antenna # ((m-1) K+1) (m-1, ..., M)

$$F_{1,m} = \frac{w_{(m-1)K+1}}{w_1} \quad (m = 1,\ldots,M) \tag{9}$$

$$G_{m,k} = \frac{w_{(m-1)K+k+1}}{w_{(m-1)K+1}} \quad (m = 1,\ldots,M, k = 1,\ldots K) \tag{10}$$

[0038] Since fading correlation is high within a group, $|G_{m,k}| = 1$ can be assigned. Specifically, it can be considered that the change due to fading is small within a group, and it is sufficient to take into consideration only change in phase. In order to keep total transmission power constant (=1.0), $F_{1,m}$ must be normalized as follows.

$$F'_{1,m} = \frac{F_{1,m}}{\sqrt{\frac{1}{KM}\sum_{j=1}^{M}|F_{1,j}|^2}}$$

[0039] Next, the fluctuation rate of fading is described.

[0040] Fading fluctuation rate is expressed by Doppler frequency.

$$f_d = \frac{v}{\lambda}$$

[0041] In the equation described above, v is the travel speed of a mobile station and λ is the carrier wavelength. For example, if a carrier frequency is 2GHz and the travel speed of a mobile station is 60km/h, f_d becomes approximately 111Hz. However, the angle of arrival of an incoming wave changes as the mobile station travels. For example, if the mobile station travels at a speed of 200km/h at a place 200 meters ahead, the input angle changes by approximately 15 degrees per second. In this way, the fading fluctuation rate is higher by several tens of times to several hundreds of times than the fluctuation rate of an input angle. According to W-CDMA standards, a slot length is 666.7μs and the

update speed of feedback information is 1500Hz. Therefore, if information about fading is not updated for each slot, a track characteristic degrades. However, there is no need to feedback information about input angle for each slot. For example, there will be no problem if information is updated for every 15 slots (=one frame) .

[0042] By utilizing the difference in the fluctuation rates of the control information described above, a feedback amount of information can be reduced without performance degradation. Specifically, an inter-group antenna control amount changing at a high speed is updated and fed back in a short cycle, while each intra-group antenna control amount changing slowly compared with the inter-group antenna control amount is updated and fed back in a longer cycle. In other words, since the change of inter-group diversity control with a low fading correlation is faster than that of the data speed of feedback information, the frequency of updates is made large. However, since the change of intra-group diversity control with a high fading correlation is slower than that of the data speed of feedback information, the frequency of updates is made small.

[0043] Since each intra-group antenna control amount has been related to the angle of the mobile station with respect to the base station, in a macro-cell system with a relatively large cell radius, the deviation of an input angle becomes negligibly small. Therefore, a specific intra-group antenna control amount can also be used as the intra-group antenna control amount of another group. Specifically, transmitting only the intra-group control information of one specific group and controlling the antennas in the other group using this information can further reduce an amount of feedback information.

[0044] Fig. 4 shows the configuration of one preferred embodiment of the present invention.

[0045] A case where the number of antennas N=4 and the number of antenna groups M=2 is described. Apilot signal generation unit 30 generates N=4 pilot signals $P_1(t)$, $P_2(t)$, $P_3(t)$ and $P_4(t)$, and each of the signals is transmitted from one of transmitting antennas 31. These pilot signals use mutually orthogonal bit sequences.

[0046] Each transmitting antenna 31 transmits the pilot signal to a mobile station. In the mobile station, a receiving antenna 32 receives the four pilot signals transmitted from each of four transmitting antennas, and a control amount calculation unit 33 estimates the channel of signals transmitted from each transmitting antenna 31 using the respective pilot signal. As a result, the channel impulse response vector is obtained from each signal and a weight vector that maximizes equation (5) is calculated. Since a method for calculating this weight vector is already publicly known, the description is omitted. When the weight vector is calculated, the control amount calculation unit 33 transfers the vector to a multiplex unit 34 as feedback information. The multiplex unit 34 multiplexes the feedback information with an upward data signal and transmits the information from a transmitting antenna 35. In a base station, a receiving antenna 36 receives the signal from the mobile station, and a feedback information extraction unit 37 extracts the feedback information from the signal. The extracted feedback information is inputted to an amplitude/phase control unit 38, each weight coefficient W_1, W_2 and w_3 included in the feedback information is multiplied to the respective downward transmitting data signal of each corresponding antenna, and the transmitting antennas 31 transmit the downward transmitting data signals. In this way, in this preferred embodiment, a closed loop for performing transmitting diversity control, including a base station and a mobile, is implemented.

[0047] Fig. 5 shows examples of a downlink pilot signal pattern in this preferred embodiment.

[0048] If each corresponding code is multiplied by each of the pilot signals P_1 through P_4 shown in Fig. 5, and the products of the entire pilot signal pattern are added up the result "0" is obtained. Specifically, the pilot signals P_1 through P_4 form a mutually orthogonal code word.

[0049] Each pilot signal's amplitude and phase change independently due to fading, and the combination of these signals is received by the antenna of a mobile station. A mobile-station receiver can calculate the channel response estimation values h_1, h_2, h_3 and h_4 of each pilot signal by correlating the incoming pilot signals with corresponding pilot signals $P_1(t)$, $P_2(t)$, $P_3(t)$ and $P_4(t)$, respectively, that are stored in advance on the mobile station side and by averaging the obtained correlations.

[0050] Fig. 6 shows both an example configuration of base-station transmitting antennas according to this preferred embodiment and antenna control information thereof.

[0051] Fig. 6A shows the transmitting antenna configuration of a base station. It is assumed that antennas ANT1 and ANT2 form group 1, and antennas ANT3 and ANT4 form group 2. It is also assumed that antennas ANT1 and ANT3 are the reference antenna of groups 1 and 2, respectively. It is further assumed that antenna ANT1 is also the reference antenna of all the groups 1 and 2. Antennas ANT1 and ANT2 are located apart from each other by one wavelength. Antennas ANT3 and ANT4 are also located apart from each other by one wavelength. Antennas ANT1 and ANT3 are located apart from each other by 20 wavelengths. Antennas ANT2 and ANT4 are also located apart from each other by 20 wavelengths.

[0052] Here, the spatial correlative characteristic of a base-station antenna is described.

[0053] If the input angles of signals from mobile stations are uniformly distributed with dispersion $\Delta\phi$, the envelope correlation coefficient of input waves is expressed as follows. In the equation, d represents the distance between two antennas.

$$\rho = \left(\frac{\sin X}{X} \right)$$

$$X = \frac{\pi d \Delta\phi}{\lambda}$$

[0054] The angle dispersion $\Delta\phi$ of each input signal observed at the base station in a macro-cell environment is approximately 3 degrees. Fig. 7 shows the envelope correlation coefficient in this case. It is seen from Fig. 7 that at $d \simeq 19\lambda$ the input signals become uncorrelated. Therefore, according to the present invention, fading correlation can be made low by setting the distance between antenna groups to approximately 19 wavelengths or more. Fading correlation can also be made high by setting the distance between antennas in each group to one wavelength or less.

[0055] However, fading correlation is affected by a variety of factors, such as the height at which the antenna is installed, the size of the antenna and the like. Therefore, it is acceptable if the antennas are installed so that the distance between any two antennas in the same group is approximately the wavelength of an incoming signal. However, a person having ordinary skill in the art should set the distance between groups so that fading correlation is almost "0" in any situation.

[0056] Description will return to Fig. 6. In the following description it is assumed that amplitude is not controlled and only phase is controlled. Specifically, only a phase amount ϕ_i is controlled by assigning a_1=1 to $w_i=a_i e^{j\phi_i}$. As shown in Fig. 6B, each of the control amount ϕ_1 of antenna ANT2 using antenna ANT1 as a reference, the control amount ϕ_2 of antenna ANT4 using antenna ANT3 as a reference and the control amount ϕ_3 of antenna ANT3 using antenna ANT1 as a reference is quantized and is transmitted to the base station as feedback information. If each of the control amounts is quantized using one bit, for example, the setting is as follows.

$$\begin{aligned} &\frac{-\pi}{2} < \phi_i \le \frac{\pi}{2} \Rightarrow \phi_i^Q = 0 \\ &\frac{\pi}{2} < \phi_i \le \frac{3\pi}{2} \Rightarrow \phi_i^Q = \pi \end{aligned} \tag{11}$$

[0057] In the expression, ϕ_i^Q is a quantized control amount.

[0058] Figs. 8 through 11 show examples of the transmission format of feedback information in this preferred embodiment.

[0059] It is assumed that if ϕ_i^Q=0, feedback information b_i=0 and that if $\phi_i^Q=\pi$, feedback information b_i=1. As shown in Fig. 8, this feedback information is multiplexed with an upward channel so that the transmission rate of b_3 may become higher than the transmission rate of b_1 or b_2 and is transmitted to a base station. One frame of length 10ms is composed of 15 slots in compliance with the W-CDMA frame format. This transmission format transmits feedback information of one bit in each slot. Format1 transmits both one b_1 and one b_2 in one frame, and format2 transmits both two b_1 and two b_2 in one frame.

[0060] In the base station, the phase control of each transmitting antenna is conducted using the feedback information received in an uplink channel. A corresponding antenna is directly controlled by the feedback information received in the immediately previous slot. In this case, antennas other than the corresponding antenna store the latest feedback information and use the information for their control.

[0061] However, ANT4 shown in Fig. 6A is controlled not only by control amount d2, but also by the control amount d3 of ANT 3. Specifically, ANT4 is frequently controlled by d3 and is also controlled by d2 less frequently. This description also applies to ANT4 shown in Fig. 6B.

[0062] Filtering feedback information can also reduce the number of transmission errors and the number of quantization errors. For example, for the filtering, a method using the average value of the control amount of the feedback information received in the immediately previous slot and the control amount of the feedback information received in receiving slots before the immediately previous slot is used.

[0063] As the feedback information of an intra-group antenna control amount, an updated control amount is transmitted every time the feedback information is transmitted. However, for example, alternatively, in the same frame, the same feedback information can also be repeatedly transmitted. In this case, the number of transmission errors in the base station can be reduced by combining a plurality of pieces of feedback information received in the frame.

[0064] Since each intra-group antenna control amount relates to the angle of a mobile station against the base station

in a macro-cell system with a to some extent large cell radius, the deviation of the input angle within a group is negligibly small. Therefore, if control is exercised within each group using the same intra-group antenna control amount, there is no problem. Therefore, transmitting only the intra-group control information of one specific group and controlling other groups using this information can further reduce an amount of feedback information.

[0065] Fig. 9 shows a feedback information transmission format used to transmit only b_1 as intra-group control information. Format3 transmits two b_1 in one frame and format 4 transmits four b_1 in one frame.

[0066] In this preferred embodiment too, as the feedback information of an intra-group antenna control amount, an updated control amount can be transmitted every time the feedback information is transmitted. Alternatively, for example, the same feedback information can be repeatedly transmitted within the same frame.

[0067] Another transmission format in which a control amount calculated in a mobile station is quantized using a plurality of bits is described below.

[0068] Fig. 10 shows the feedback information transmission format in which b_1 and b_3 are quantized using three bits and four bits, respectively. Tables 1 and 2 of Fig. 11 show the correspondence between the feedback information b_3 of an inter-group antenna control amount and a control amount. Table 3 shows the correspondence between the feedback information b_1 of an intra-group antenna control amount and a control amount.

[0069] In this example, only the feedback information of an intra-group antenna control amount b_1 is transmitted using the format shown in Fig. 9. As is clearly seen from Tables 1 and 2 of Fig. 11, feedback information bit b_3 is composed of four bits; three bits of $b_3(3)$ through $b_3(1)$ representing a phase control amount and one bit of $b_3(0)$ representing an amplitude control amount. Format5 shown in Fig. 10 includes feedback information bit b_3 in one frame. However, three words of feedback information bit b1 are composed of three bits of b_1 (2) through b_1 (0) representing a phase control amount. According to formats shown in Fig. 10, three bits of feedback information bit b_1 are distributed and located in one frame, and all the three bits together form one word.

[0070] Fig. 12 shows an example configuration of a mobile station that transmits feedback information to a base station according to the formats shown in Figs. 8 through 11.

[0071] On receipt of a signal from a base station via its receiving antenna, a mobile station branches the receiving signal into two signals and inputs one signal and the other signal to a data channel despreading unit 41 and a pilot channel despreading unit 44, respectively. The data channel dispreading unit 41 despreads the data channel signal and inputs the signal to both a channel estimation unit 42 and a receiver 43. The receiver 43 reproduces the downlink data signal, based on the channel estimation result of the channel estimation unit 42 and presents the signal to a user as voice or data. The pilot channel dispreading unit 44 despreads the incoming signal using a pilot channel dispreading code and inputs the signal to a channel estimation unit 45. The channel estimation unit 45 correlates the despread signal to each pilot signal pattern and obtains channel estimation values $H=[h_1, h_2, h_3$ and $h_4]$ for paths from each transmitting antenna to the mobile station. A control amount calculation unit 46 calculates a weight vector based on these channel estimation values and determines feedback information to be transmitted. A multiplex unit 47 multiplexes this feedback information with an upward control channel. A data modulation unit 48 modulates the feedback information. A spreading modulation unit 49 spread-modulates the feedback information. Then, the feedback information is transmitted to the base station from a transmitting antenna 50.

[0072] In Fig. 13, the same reference numbers are attached to the same constituent components as those in Fig. 4 and their descriptions are omitted.

[0073] In this preferred embodiment, a base station uses both uplink feedback information and an uplink channel arriving method estimation result as intra-group antenna control information. In the base station, input direction estimation units 62 and 63 estimate the arriving direction of an incoming signal based on an uplink receiving signal received by an array antenna (a plurality of antennaslements used in transmission diversity: transmitting/receiving antenna 60). Since arriving direction strongly depends on the angle of a mobile station against a base station, a method for setting the direction of a downlink transmitting beam (direction in which the strength of a wave transmitted from an antenna is large) to this uplink signal input direction is known. However, in a system where uplink and downlink frequencies are different, this assumption does not always hold true and depends on the propagation environment.

[0074] Upon receipt of the uplink feedback information via an antenna 60, a receiving processing unit 61 performs the despeading and the like of the uplink feedback information and relays the information to a feedback information extraction unit 37. When the feedback information extraction unit 37 extracts a control amount from the uplink feedback information, an amplitude/phase control unit 38' compares the control amount with the arriving direction estimation value and determines to use either the control amount received from the uplink line or the arriving direction estimation value. Then, the unit 38' controls the amplitude/phase of a transmitting signal.

[0075] As shown in Fig. 14, in this preferred embodiment, if the intra-group phase difference is not within a specific range $[\theta-\Delta,\theta-\Delta]$ with the arriving direction estimation result θ of the uplink channel as a center, control is exercised using only the arriving direction estimation result θ since the control amount by the upward feedback information is related to an uplink channel arriving direction estimation result θ. Specifically, if the control amount in the feedback information is too far from the arriving direction estimation result θ, it is judged that a bit error or the like has occurred

during transmission of the feedback information, and the feedback information is inaccurate. Then, the feedback information is discarded and only phase is controlled using the arriving direction estimation result θ.

[0076] Alternatively, a control amount in the uplink feedback information of intra-group phase difference information can be sampled for a prescribed time period. If it is judged that variance of the samples is large (for example, specifically, if the samples are dispersed more widely than a specific predetermined threshold value), control can be exercised using only the arriving method estimation result θ without utilizing the feedback information.

[0077] Fig. 15 shows the configuration of the third preferred embodiment of the present invention.

[0078] In Fig. 15, the same reference numbers are attached to the same components as those in Fig. 4, and their descriptions are omitted.

[0079] In this case, the transmitting powers of pilot signals P_1 and P_3 are set smaller than the transmitting powers of pilot signals P_2 and P_4, respectively. In this preferred embodiment, this is implemented by multiplying pilot signals P_2 and P_4 by a coefficient α ($0<\alpha<1$). Although pilot signals P_2 and P_4 are needed to estimate channel impulse response vectors $\underline{h}_2$ and $\underline{h}_4$, $\underline{h}_2$ and $\underline{h}_4$ have high fading correlations to $\underline{h}_1$ and $\underline{h}_3$, respectively. Therefore, $\underline{h}_2/\underline{h}_1$ and $\underline{h}_4/\underline{h}_3$ that are normalized by them strongly depend on an angle of the mobile station against the base station. Since these values fluctuate slowly compared with fading fluctuation, estimation accuracy can be improved by taking a long time average of pilot signals P_2 and P_4 even if incoming power on the mobile station side is low. Both ϕ_1 and ϕ_2 are calculated as follows.

$$\phi_1 = \underline{h}_2/\underline{h}_1,\ \phi_2 = \underline{h}_4/\underline{h}_3 \tag{12}$$

[0080] Since interference to data signals by pilot signals can be suppressed to a low level by setting the transmitting powers of pilot signals P_2 and P_4 to a low level, transmission capacity can be increased.

[0081] Since both $\underline{h}_2/\underline{h}_1$ and $\underline{h}_4/\underline{h}_3$ depend on the angle of the mobile station against the base station and fluctuate more slowly than a fading fluctuation, estimation accuracy can be improved by taking a long time average of pilot signals P_2 and P_4 even if an incoming power is low. For example, estimation values $\phi_1(n)$, $\phi_2(n)$ and $\phi_3(n)$ at the n-th slot can be calculated as follows. In these equations, N is the estimated average number of slots of estimation values $\phi_1(n)$ and $\phi_2(n)$.

$$\phi_1(n) = \frac{1}{N}\sum_{i=0}^{N-1}\frac{\underline{h}_2(n-i)}{\underline{h}_1(n-i)}$$

$$\phi_2(n) = \frac{1}{N}\sum_{i=0}^{N-1}\frac{\underline{h}_4(n-i)}{\underline{h}_3(n-i)}$$

$$\phi_3(n) = \frac{\underline{h}_3(n)}{\underline{h}_1(n)}$$

[0082] In this way, when both ϕ_1 and ϕ_2 are calculated by taking a N-times time (number of slots) average of ϕ_3, the same estimation accuracy as that of ϕ_3 can be obtained even if α = 1/N. Specifically, in case N=4, α = 1/4 can be assigned.

Industrial Applicability

[0083] If the number of transmitting antennas is increased by utilizing differences in the fluctuation rate of control information, the following effects can be obtained.

- The increase in the amount of upward feedback information can be suppressed.
- Characteristics degrade little in the case of a high fading frequency.
- The antenna installation space of a base station can be reduced.

Claims

1. A transmitting diversity communications apparatus, including a base station adopting a transmitting diversity method, for controlling transmitting signals according to information from a mobile station, comprising:

   antenna means composed of a plurality of antenna groups, each group consisting of a plurality of antennas located close to one another so that fading correlation between the antennas is high, and the antenna groups are located apart from one another so that fading correlation between the groups is low; and
   control means for receiving both first control information for intra-group antenna control, with a low transfer rate and second control information for inter-antenna group control, with a high transfer rate that are transmitted from a mobile station, and controlling a phase of a signal transmitted by the antenna means.

2. The transmitting diversity communications apparatus according to claim 1, wherein the mobile station determines a control amount of the phase using pilot signals transmitted from the base station.

3. The transmitting diversity communications apparatus according to claim 1, wherein said control means also controls amplitude in addition to the phase.

4. The transmitting diversity communications apparatus according to claim 3, wherein the mobile station determines control amounts of both the phase and amplitude using pilot signals transmitted from the base station.

5. The transmitting diversity communications apparatus according to claim 4, wherein the mobile station estimates a channel response from each antenna to the mobile station by correlating a pilot signal from the base station to a known pilot signal on a mobile station side and calculating the control amount using this channel response estimation value.

6. The transmitting diversity communications apparatus according to claim 1, wherein the mobile station transmits information describing the difference in channel response estimation values between each intra-group antenna of said antenna means and a reference antenna and information describing the difference in channel response estimation values between each antenna group and a reference antenna of a specific antenna group to the base station as the first and second control information, respectively.

7. The transmitting diversity communications apparatus according to claim 1, wherein the mobile station transmits control information about each antenna group and control information about an intra-group antenna within a specific antenna group to the base station as the second and first control information, respectively.

8. The transmitting diversity communications apparatus according to claim 1, wherein said control means controls the transmitting of a signal from the base station using an input direction estimation result of an uplink channel signal in addition to the first and second control information.

9. The transmitting diversity communications apparatus according to claim 8, wherein if transmitting signal control amounts obtained from the first and second control information do not fall within a specific range with an arriving direction estimation result of the uplink channel signal as a center, transmission is controlled using the input direction estimation result.

10. The transmitting diversity communications apparatus according to claim 8, wherein if transmitting signal control amount dispersion obtained from the first control information is larger than a prescribed value, transmission is controlled using only an arriving direction estimation result.

11. The transmitting diversity communications apparatus according to claim 1, wherein control is exercised by a filtering result using both currently received first and second information and one or more previously received first and second control information.

12. The transmitting diversity communications apparatus according to claim 1, wherein the power of a signal transmitted from an antenna other than a reference antenna is set at a lower level than the power of a signal transmitted from a reference antenna of each antenna group.

13. A transmitting diversity communications apparatus, including a base station adopting a transmitting diversity meth-

od, for controlling transmitting signals according to information from a mobile station, comprising:

antenna means composed of a plurality of antenna groups, each group consisting of a plurality of antennas located close to one another so that fading correlation between the antennas is high, and the antenna groups are located apart from one another so that fading correlation between the groups is low; and
control means for receiving both first control information for intra-group antenna control, with a low transfer rate and second control information for inter-antenna group control, with a high transfer rate that are transmitted from a mobile station, and controlling both amplitude and phase of a signal transmitted by the antenna means.

14. A mobile station of a transmitting diversity communications apparatus, including a base station adopting a transmitting diversity method, for controlling transmitting signals according to information from a mobile station, comprising:

receiving means for receiving a signal transmitted from an antenna means composed of a plurality of antenna groups, each group consisting of a plurality of antennas located close to one another so that fading correlation between the antennas is high, and the antenna groups are located apart from one another so that fading correlation between the groups is low;
antenna specifying means for identifying an antenna that has transmitted the received signal; and
transmitting means for transmitting first control information about intra-group antenna control of the received signal to the base station at a prescribed transfer rate and transmitting second control information about inter-group antenna control of the received signal to the base station at a higher transfer rate than the prescribed transfer rate.

15. A transmitting diversity communications method, including a base station adopting a transmitting diversity method, for controlling transmitting signals according to information from a mobile station, comprising:

providing a plurality of antenna groups, each group consisting of a plurality of antennas, placing the antennas in the same group close to one another so that fading correlation between the antennas in the same group is high and placing the antenna groups apart from one another so that fading correlation between the groups is low; and
receiving both first control information for intra-group antenna control, with a low transfer rate and second control information for inter-antenna group control, with a high transfer rate that are transmitted from a mobile station and controlling the phase of a signal transmitted by the antenna unit.

16. A communications system for controlling the phase of each of transmitting signals transmitted from a plurality of antennas of a base station according to phase control information from a mobile station, wherein
some of the plurality of antennas of the base station have a location relation in which, with respect to one antenna, other antennas are placed where fading correlation is high, and where fading correlation is low, and
the mobile station transmits phase control information about an antenna located in the position having a high fading correlation and phase control information about an antenna located in the position having a low fading correlation to the base station with low frequency and high frequency, respectively.

17. A communications system for controlling the phase of each of transmitting signals transmitted from a plurality of antennas of a base station according to phase control information from a mobile station, wherein
some of the plurality of antennas of the base station have a location relation in which, with respect to one antenna, other antennas are placed where fading correlation is high, and where fading correlation is low, and
the mobile station transmits phase control information about an antenna located in the position having a high fading correlation to the base station with lower frequency than frequency of phase control information of an antenna located in the position having a low fading correlation.

18. A communications system for controlling the phase of each of transmitting signals transmitted from a plurality of antennas of a base station according to phase control information from a mobile station, wherein
all the plurality of antennas except a specific antenna of the base station are located in positions having a specific fading correlation to the antenna, and
the mobile station transmits phase control information about the antennas except the specific antenna to the base station with frequency corresponding to the specific fading correlation.

19. A communications system for controlling the phase of each of transmitting signals transmitted from a plurality of

antennas of a base station according to phase control information from a mobile station, wherein

all the plurality of antennas except a specific antenna of the base station are located in positions having a high fading correlation to the antenna, and

the mobile station transmits phase control information about the antennas except the specific antenna to the base station with low frequency.

20. A communications system for controlling the phase of each of transmitting signals transmitted from a plurality of antennas of a base station according to phase control information from a mobile station, wherein

all the plurality of antennas except a specific antenna of the base station are located in positions having a low fading correlation to the antenna, and

the mobile station transmits phase control information about all the antennas except the specific antenna to the base station with high frequency.

21. A mobile station of a communications system for controlling the phase of each of signals transmitted from a plurality of antennas on a base station side where some of the plurality of antennas and the other antennas except a specific antenna are located in positions having a high fading correlation and in positions having a low fading correlation, respectively, to the antenna according to phase control information from a mobile station, comprising:

control means for generating phase control information about the plurality of antennas; and
transmitting means for transmitting phase control information about an antenna located in a position having a high fading correlation and phase control information of an antenna located in a position having a low fading correlation to the base station with low frequency and high frequency, respectively.

22. A mobile station of a communications system for controlling the phase of each of signals transmitted from a plurality of antennas on a base station side where some of the plurality of antennas and the other antennas except a specific antenna are located in positions having a high fading correlation and in positions having a low fading correlation, respectively, to the antenna according to phase control information from a mobile station, comprising:

control means for generating phase control information about the plurality of antennas; and
transmitting means for transmitting phase control information about an antenna located in a position having a high fading correlation to the base station with lower frequency than frequency of phase control information of an antenna located in a position having a low fading correlation.

23. A mobile station of a communications system for controlling the phase of each of transmitting signals transmitted from a plurality of antennas on a base station side where all the plurality of antennas except a specific antenna are located in positions having a specific fading correlation to the antenna according to phase control information from a mobile station, comprising:

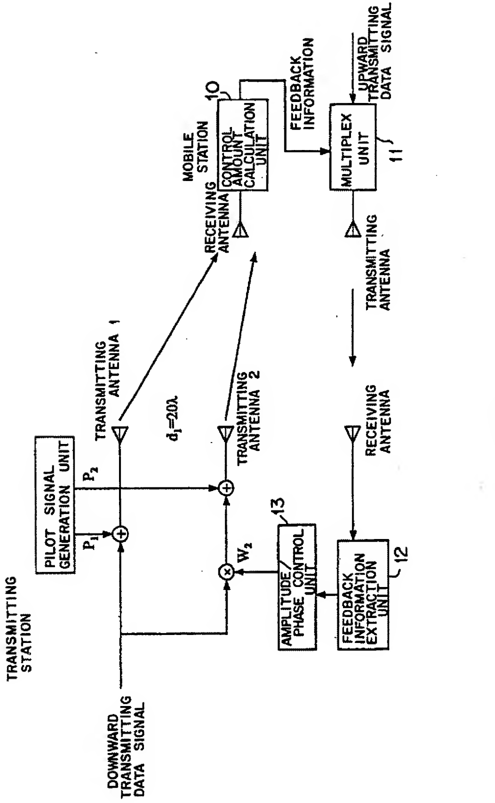
control means for generating phase control information about the plurality of antennas; and
transmitting means for transmitting the corresponding antenna phase control information to the base station with frequency corresponding to the fading correlation.

24. A mobile station of a communications system for controlling the phase of each of signals transmitted from a plurality of antennas on a base station side where the other of the plurality of antennas are located in positions having a high fading correlation with one antenna according to phase control information from a mobile station, comprising:

control means for generating phase control information about the plurality of antennas; and
transmitting means for transmitting antenna phase control information about all the antennas except the specific antenna to the base station with low frequency.

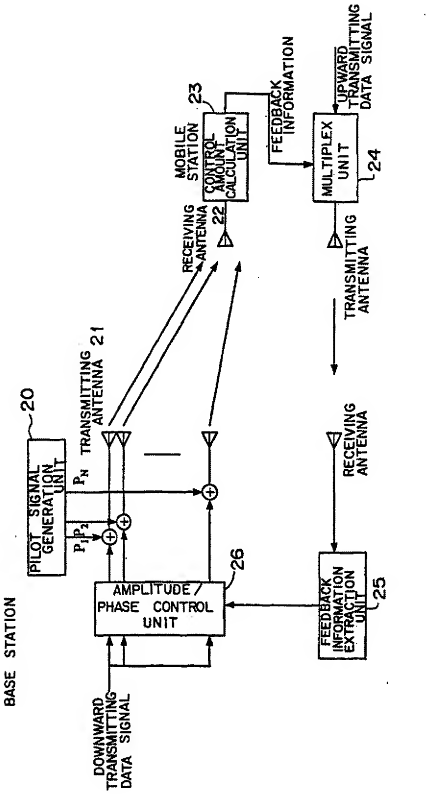
25. A mobile station of a communications system for controlling the phase of each of signals transmitted from a plurality of antennas on a base station side where all the plurality of antennas except a specific antenna are located in positions having a low fading correlation to the antenna according to phase control information from a mobile station, comprising:

control means for generating phase control information about the plurality of antennas; and
transmitting means for transmitting phase control information about all the antennas except a specific antenna to the base station with high frequency.



TRANSMITTING STATION
DOWNWARD TRANSMITTING DATA SIGNAL
PILOT SIGNAL GENERATION UNIT
P1
P2
TRANSMITTING ANTENNA 1
d_1=20λ
TRANSMITTING ANTENNA 2
W2
AMPLITUDE/PHASE CONTROL UNIT
13
FEEDBACK INFORMATION EXTRACTION UNIT
12
RECEIVING ANTENNA
MOBILE STATION
RECEIVING ANTENNA
CONTROL AMOUNT CALCULATION UNIT
10
FEEDBACK INFORMATION
MULTIPLEX UNIT
11
UPWARD TRANSMITTING DATA SIGNAL
TRANSMITTING ANTENNA

F I G. 1


BASE STATION
DOWNWARD TRANSMITTING DATA SIGNAL
AMPLITUDE / PHASE CONTROL UNIT
26
PILOT SIGNAL GENERATION UNIT
20
P1
P2
PN
TRANSMITTING ANTENNA
21
RECEIVING ANTENNA
22
MOBILE STATION
CONTROL AMOUNT CALCULATION UNIT
23
FEEDBACK INFORMATION
MULTIPLEX UNIT
24
UPWARD TRANSMITTING DATA SIGNAL
TRANSMITTING ANTENNA
RECEIVING ANTENNA
FEEDBACK INFORMATION EXTRACTION UNIT
25

F I G. 2

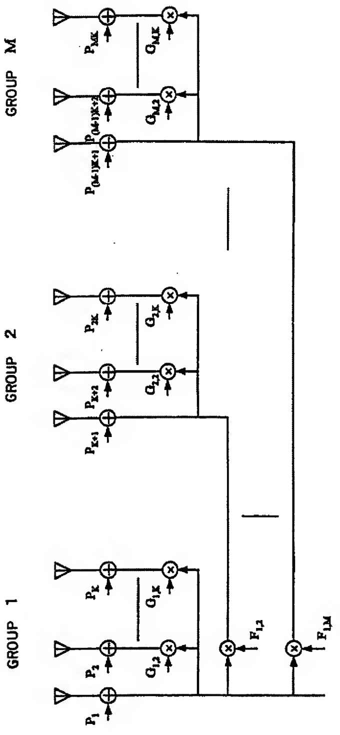
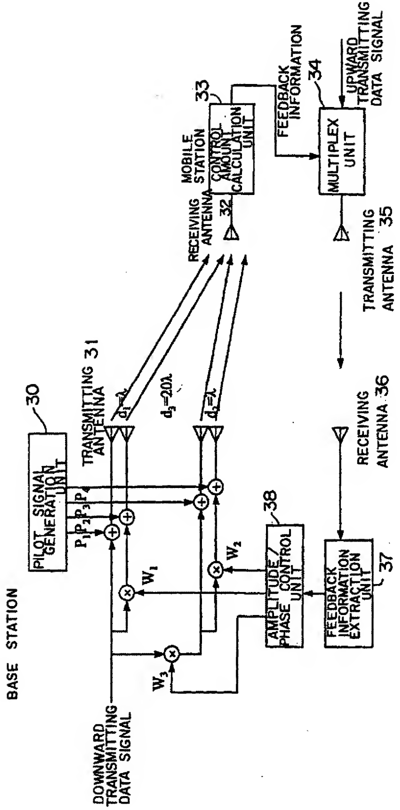
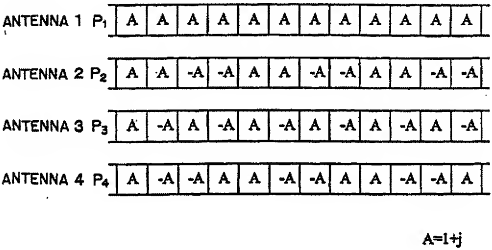

GROUP 1
GROUP 2
GROUP M
P1
P2
PK
PK+1
PK+2
P2K
P(M-1)K+1
P(M-1)K+2
PMK
G1,2
G1,K
G2,2
G2,K
GM,2
GM,K
F1,2
F1,M

FIG. 3

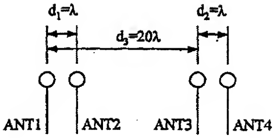


BASE STATION
PILOT SIGNAL GENERATION UNIT
30
P_1 P_2 P_3 P_4
TRANSMITTING ANTENNA 31
$d_1=\lambda$
$d_3=20\lambda$
$d_2=\lambda$
DOWNWARD TRANSMITTING DATA SIGNAL
W_1
W_2
W_3
AMPLITUDE / PHASE CONTROL UNIT
38
FEEDBACK INFORMATION EXTRACTION UNIT
37
RECEIVING ANTENNA 36
MOBILE STATION
RECEIVING ANTENNA
32
CONTROL AMOUNT CALCULATION UNIT
33
FEEDBACK INFORMATION
MULTIPLEX UNIT
34
UPWARD TRANSMITTING DATA SIGNAL
TRANSMITTING ANTENNA 35

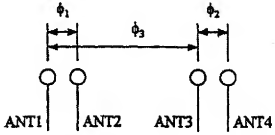
F I G. 4


ANTENNA 1 P_1 A A A A A A A A A A A A
ANTENNA 2 P_2 A A -A -A A A -A -A A A -A -A
ANTENNA 3 P_3 A -A A -A A -A A -A A -A A -A
ANTENNA 4 P_4 A -A -A A A -A -A A A -A -A A
A=1+j

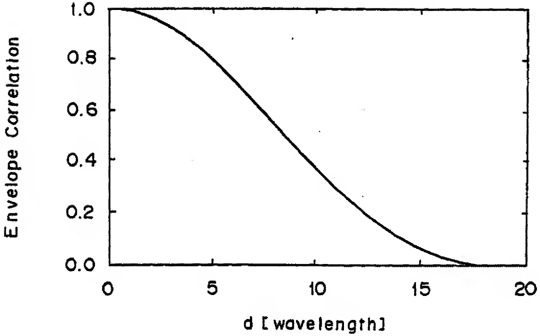
F I G. 5



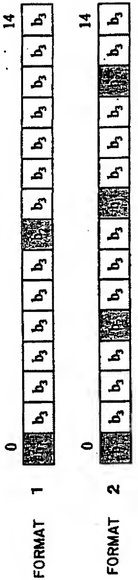
F I G. 6A



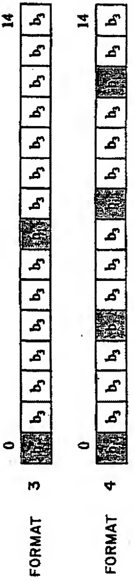
F I G. 6B


1.0
0.8
0.6
0.4
0.2
0.0
Envelope Correlation
0
5
10
15
20
d [wavelength]

F I G. 7



F I G. 8



F I G. 9

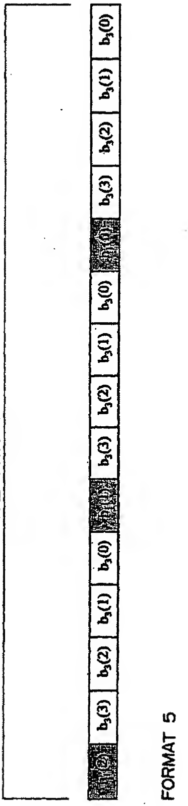


FIG. 10

TABLE 1. FEEDBACK BIT ($b_3(0)$)

$b_3(0)$	ANTENNA 1 AMPLITUDE	ANTENNA 2 AMPLITUDE
0	0.2	0.8
1	0.8	0.2

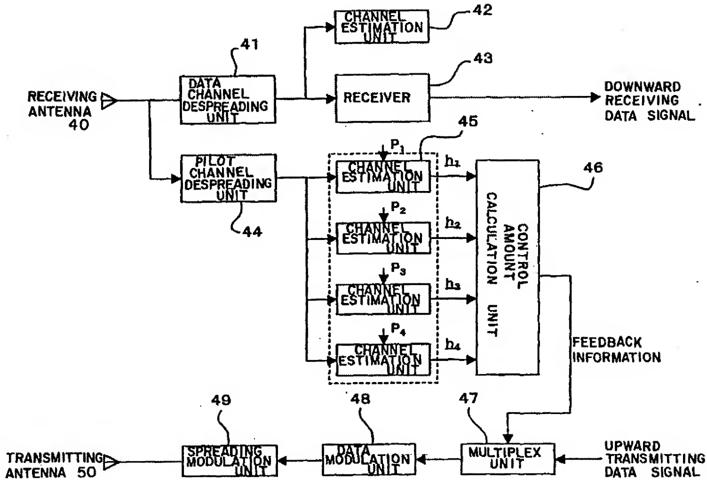
TABLE 2. FEEDBACK BIT ($b_3(3)$, $b_3(2)$, $b_3(1)$)

$b_3(3)$, $b_3(2)$, $b_3(1)$	INTER- ANTENNA PHASE DIFFERENCE (DEGREE)
000	180
001	-135
010	-90
011	-45
100	0
101	45
110	90
111	135

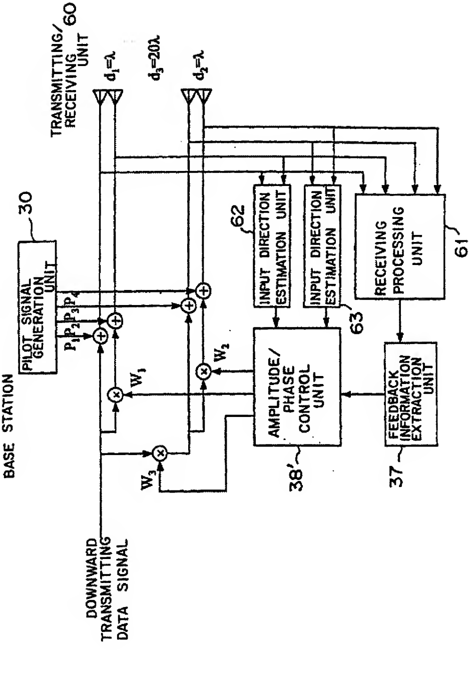
TABLE 3. FEEDBACK BIT ($b_1(2)$, $b_1(1)$, $b_1(0)$)

$b_1(2)$, $b_1(1)$, $b_1(0)$	INTER- ANTENNA PHASE DIFFERENCE (DEGREE)
000	180
001	-135
010	-90
011	-45
100	0
101	45
110	90
111	135

FIG. 11


RECEIVING ANTENNA 40
41
DATA CHANNEL DESPREADING UNIT
42
CHANNEL ESTIMATION UNIT
43
RECEIVER
DOWNWARD RECEIVING DATA SIGNAL
PILOT CHANNEL DESPREADING UNIT
44
45
P1
P2
P3
P4
CHANNEL ESTIMATION UNIT
CHANNEL ESTIMATION UNIT
CHANNEL ESTIMATION UNIT
CHANNEL ESTIMATION UNIT
h1
h2
h3
h4
CONTROL AMOUNT CALCULATION UNIT
46
FEEDBACK INFORMATION
47
MULTIPLEX UNIT
UPWARD TRANSMITTING DATA SIGNAL
48
DATA MODULATION UNIT
49
SPREADING MODULATION UNIT
TRANSMITTING ANTENNA 50

F I G. 12


BASE STATION
TRANSMITTING/
RECEIVING UNIT
60
30
PILOT SIGNAL GENERATION UNIT
P_1 P_2 P_3 P_4
$d_1=\lambda$
$d_3=20\lambda$
$d_2=\lambda$
W_1
W_2
W_3
62
INPUT DIRECTION ESTIMATION UNIT
INPUT DIRECTION ESTIMATION UNIT
63
RECEIVING PROCESSING UNIT
61
AMPLITUDE/ PHASE CONTROL UNIT
38'
FEEDBACK INFORMATION EXTRACTION UNIT
37
DOWNWARD TRANSMITTING DATA SIGNAL

F I G. 13

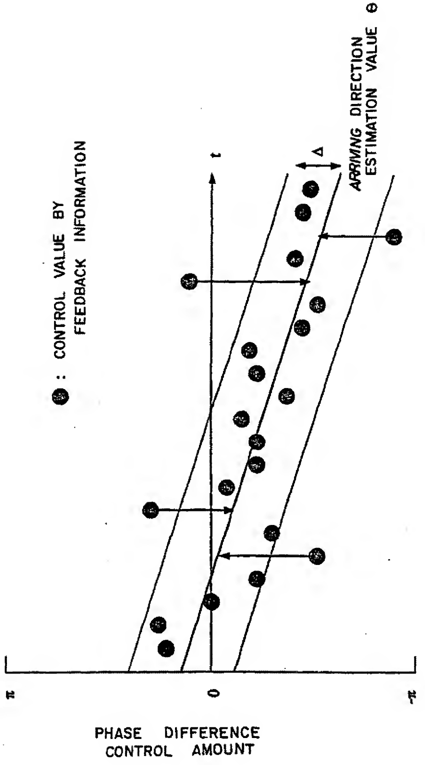

: CONTROL VALUE BY FEEDBACK INFORMATION
ARRIVING DIRECTION ESTIMATION VALUE θ
t
Δ
π
0
-π
PHASE DIFFERENCE CONTROL AMOUNT

FIG. 14

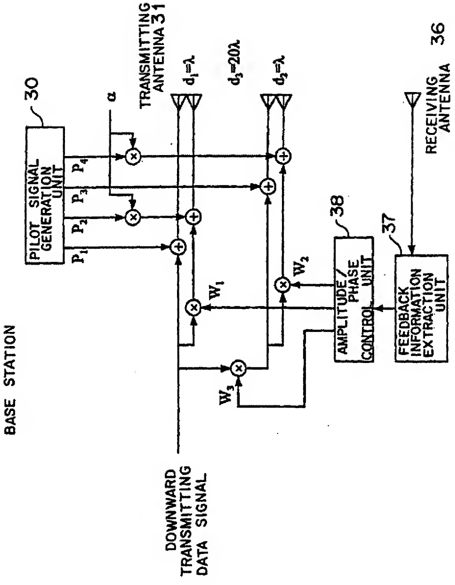

BASE STATION
PILOT SIGNAL GENERATION UNIT
30
P_1
P_2
P_3
P_4
α
TRANSMITTING ANTENNA 31
$d_1=\lambda$
$d_3=20\lambda$
$d_2=\lambda$
RECEIVING ANTENNA
36
38
AMPLITUDE / PHASE CONTROL UNIT
37
FEEDBACK INFORMATION EXTRACTION UNIT
W_1
W_2
W_3
DOWNWARD TRANSMITTING DATA SIGNAL

FIG. 15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP00/05380

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl^7 H04B 7/06, 7/10, 7/26, H01Q 3/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl^7 H01Q 3/00- 3/46, 21/00-25/04
H04B 7/00, 7/02-7/12, 7/24-7/26, 113
H04L 1/02- 1/06, H04Q7/00-7/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1922-1996 Toroku Jitsuyo Shinan Koho 1994-2000
Kokai Jitsuyo Shinan Koho 1971-2000 Jitsuyo Shinan Toroku Koho 1996-2000

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	JP 58-87928 A (Nippon Telegr. & Teleph. Corp. <NTT>), 25 May, 1983 (25.05.83) (Family: none)	20,25 1-19,21-24
A	JP 10-190537 A (NEC Corporation), 21 July, 1998 (21.07.98) (Family: none)	1-25
A	JP 9-200115 A (Toshiba Corporation), 31 July, 1997 (31.07.97) (Family: none)	1-25

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 23 October, 2000 (23.10.00)	Date of mailing of the international search report 31 October, 2000 (31.10.00)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 379 020 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
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(21) Application number: 02254685.7

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(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR IE IT LI LU MC NL PT SE SK TR
Designated Extension States:
AL LT LV MK RO SI

(71) Applicant: NATIONAL UNIVERSITY OF SINGAPORE
Singapore 119260 (SG)

(72) Inventors:
- Liang, Ying-Chang
Singapore 120301 (SG)
- Chin, Francis Po Shin
Serangoon Central Singapore 550208 (SG)

(74) Representative: Hoarton, Lloyd Douglas Charles
Forrester & Boehmert,
Pettenkoferstrasse 20-22
80336 München (DE)

(54) A wireless communication apparatus and method

(57) A method and apparatus for achieving combined beamforming and transmit diversity for frequency selective fading channels in a communication system having a base station with multiple transmit antennae and a mobile terminal with at least a single receive antenna, the method comprising the steps of: providing a signal to be transmitted; space-time encoding the signal to produce at least two separate signals, each on a respective output; feeding each output signal to a multiple access transmit processor to produce an output signal; applying respective selected transmit beamforming weights to each output signal; feeding the respective weighted signals to a signal combiner to perform a summing function of the signals and produce a signal for transmission; feeding the summed signal to each of the multiple transmit antennae for transmission; transmitting the signals over respective physical channels; receiving the transmitted signal at at least a single receive antenna; feeding the transmitted signal to a multiple access receive processor to produce an output signal; and space-time decoding the received signal.

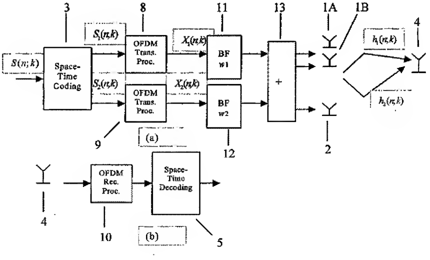


Figure5

EP 1 379 020 A1

Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates in general to wireless communication systems and, more particularly, to improving the downlink performance of wireless communication systems.

[0002] Wireless mobile communications suffer from four major impairments: path loss, multipath fading, inter-symbol interference (ISI) and co-channel interference. Adaptive antennas can be used to suppress the effects of these factors to improve the performance of wireless communication systems. There are two types of adaptive antennas: diversity antennas and beamforming antennas. In a diversity antenna system, multiple low-correlation or independent fading channels are acquired in order to compensate multipath fading, thus achieving diversity gain. Beamforming antennas, on the other hand, provide beamforming gain by making use of spatial directivity, thus compensating for path loss to a certain extent and suppressing co-channel interference.

[0003] In a diversity antenna system, the antenna spacing is usually required to be large enough, e.g., 10λ in order to obtain low-correlation/independent fading channels, especially for small angular spread environments. However, beamforming antennas need to achieve spatial directivity, so the signals received at and/or transmitted from all antennas must be correlated. This means that for beamforming antenna, the antenna spacing should usually be small, e.g. half wavelength for a uniform linear array (ULA). Because of the conflict between the required antenna spacings for diversity antenna systems and beamforming systems, a prejudice exists that diversity gain and beamforming gain cannot be achieved simultaneously.

SUMMARY OF THE INVENTION

[0004] It is an object of the present invention to seek to provide a wireless communication system benefiting simultaneously from both diversity gain and beamforming gain.

[0005] Accordingly, one aspect of the present invention provides a method of achieving transmit diversity gain in a communication system having a base station with multiple transmit antennae and a mobile terminal with a single receive antenna, the method comprising the steps of: providing a signal to be transmitted $s(n)$; space-time encoding the signal $s(n)$ to produce at least two separate signals $s_1(n),s_2(n)$, each on a respective output; feeding each output signal $s_1(n),s_2(n)$ to a zero-forcing pre-equaliser having a respective function $g_1(k)$, $g_2(k)$ to produce an output signal $x_1(n)$, $x_2(n)$; feeding the output signal $x_1(n)$, $x_2(n)$ of each pre-equaliser to a transmit antenna; transmitting the output signals $x_1(n)$, $x_2(n)$ over respective physical channels $h_1(k)$, $h_2(k)$; receiving the output signals $x_1(n)$, $x_2(n)$ at a single receive antenna; and space-time decoding the received signals, wherein the functions $g_1(k)$, $g_2(k)$ of the zero-forcing pre-equalisers are selected such that the channel responses $g_1(k)^*h_1(k)$, $g_2(k)^*h_2(k)$ of the respective physical channels $h_1(k)$, $h_2(k)$ are flat fading channels.

[0006] Preferably, the communications system is a time-division duplex system and the method includes the further step of deriving the real channel coefficients from uplink channel coefficients for use in selecting the functions $g_1(k)$, $g_2(k)$ of the pre-equalisers.

[0007] Conveniently, the step of deriving the real channel coefficients from uplink channel coefficients uses training symbols from the uplink channel.

[0008] Advantageously, the step of deriving the real channel coefficients from uplink channel coefficients uses blind techniques.

[0009] Preferably, the communications system is a frequency-division duplex system and the method includes the further step of deriving the real channel coefficients by sending a set of training symbols to the receive antenna of the mobile terminal, the mobile terminal estimating the real channel coefficients and feeding back channel coefficient information to the base station.

[0010] Another aspect of the present invention provides a base station with multiple transmit antennae for communicating with a mobile terminal having a single receive antenna over physical channels $h_1(k)$, $h_2(k)$, the base station comprising:

a space-time encoder having an input of a signal to be transmitted $s(n)$ and at least two outputs each producing a separate signal $s_1(n),s_2(n)$; at least two zero-forcing pre-equalisers, each fed by a respective output signal $s_1(n),s_2(n)$ and having a respective function $g_1(k)$, $g_2(k)$ to produce an output signal $x_1(n)$, x_2(n); and at least two transmit antennae, each being fed by the output signal $x_1(n)$, $x_2(n)$ of a respective one of the pre-equalisers, wherein the functions $g_1(k)$, $g_2(k)$ of the zero-forcing pre-equalisers are selected such that the channel responses $g_1(k)^*h_1(k)$, $g_2(k)^*h_2(k)$ of the respective physical channels $h_1(k)$, $h_2(k)$ are flat fading channels.

[0011] Preferably, the mobile terminal has a single receive antenna and a space-time decoder to decode the signals

received from the base station.

[0012] A further aspect of the present invention provides a method of achieving combined beamforming and transmit diversity for frequency selective fading channels in a communication system having a base station with multiple transmit antennae and a mobile terminal with a single receive antenna, the method comprising the steps of: providing a signal to be transmitted $S(n;k)$; space-time encoding the signal $S(n;k)$ to produce at least two separate signals $S_1(n;k), S_2(n;k)$, each on a respective output; feeding each output signal $S_1(n;k), S_2(n;k)$ to a transmit processor to produce an output signal $X_1(n;k)$, $X_2(n;k)$; applying respective selected transmit beamforming weights to each output signal $X_1(n;k)$, $X_2(n;k)$; feeding the respective weighted signals to a signal combiner to perform a summing function of the signals and produce a signal $X(n;k)$ for transmission; feeding the summed signal $X(n;k)$ to each of the multiple transmit antennae for transmission; transmitting the signals $X(n;k)$ over respective the physical channel $h(n;k)$; receiving the received signal $Y(n;k)$ at a single receive antenna; feeding the received signal $Y(n;k)$ to a receive processor to produce an output signal; and space-time decoding the received signal.

[0013] Preferably, the respective transmit beamforming weights are selected as the eigenvectors corresponding to the two largest eigenvalues of the downlink channel covariance matrix (DCCM) of the physical channel $h(n;k)$.

[0014] Conveniently, the physical channel $h(n;k)$ consists of two time-delayed rays, $h_1(n;k)$ and $h_2(n;k)$, and the transmit processors do not add cyclic prefixes and one of the output signals from the transmit processors is delayed by $\Delta\tau$ before the respective selected transmit beamforming weight is applied thereto, the beamforming weights being chosen such that the delayed signal or its inverse fast Fourier transform (IFFT) only goes through one channel $h_1(n;k)$ between the base station multiple transmit antennae and the receive antenna, whilst the undelayed signal or its IFFT only goes through another channel $h_2(n;k)$ between the base station multiple transmit antennae and the receive antenna, thereby creating two different channels which can be space-time decoded to recover the transmitted signal.

[0015] Advantageously, the physical channel $h(n;k)$ consists of two time-delayed clustered rays, $h_1(n;k)$ and $h_2(n;k)$, the transmit processors have a cyclic prefix length of $\Delta\psi$ and one of the output signals from the transmit processors is delayed by ψ before the respective selected transmit beamforming weight is applied thereto, the beamforming weights being chosen such that the delayed signal or its inverse fast Fourier transform (IFFT) only goes through one channel $h_1(n;k)$ between the base station multiple transmit antennae and the receive antenna, whilst the undelayed signal or its IFFT only goes through another channel $h_2(n;k)$ between the base station multiple transmit antennae and the receive antenna, thereby creating two different channels which can be space-time decoded to recover the transmitted signal.

[0016] Preferably, the method comprises the further steps of: estimating a power-delay-DOA profile for the channel $h(n;k)$; and, based on the profile: determining the cyclic prefix length, $\Delta\psi$, to be added by the transmit processors; determining the delay ψ; and determining the transmit beamforming weights.

[0017] Advantageously, the method comprises the further step of estimating the downlink channel covariance matrix (DCCM) from the uplink channel covariance matrix (UCCM) to construct transmit beamforming weights.

[0018] Conveniently, the method comprises the further steps of: estimating the downlink channel covariance matrix (DCCM) from the uplink channel covariance matrix (UCCM) to construct transmit beamforming weights; estimating a power-delay-DOA profile for channel $h(n;k)$; and, based on the profile: determining the length, $\Delta\psi$, of the cyclic prefix to be added by the transmit processors; determining the delay ψ; and determining the transmit beamforming weights.

[0019] A further aspect of the present invention provides a base station with multiple transmit antennae for communicating with a mobile terminal having a single receive antenna over physical channel $h(n;k)$ having two time-delayed rays, $h_1(n;k)$ and $h_2(n;k)$, the base station comprising:

a space-time encoder having an input of a signal to be transmitted and at least two outputs each producing a separate signal; at least two transmit processors each receiving one of the outputs from a respective space-time encoder; at least two transmit beamformers each receiving an output from a respective transmit processor and applying a transmit beamforming weight thereto; a signal combiner receiving signals from the beamformers and operable to perform a summing function of the signals from the beamformers and produce a signal for transmission by the multiple transmit antennae.

[0020] Preferably, a delay of $\Delta\tau$ is interposed between one of the transmit processor outputs and a beamformer to delay the signal output from the transmit processor by $\Delta\tau$ before the respective selected transmit beamforming weight is applied thereto, wherein the transmit processors do not add cyclic prefixes.

[0021] Conveniently, a delay of ψ is interposed between one of thetransmit processor outputs and a beamformer to delay the signal output from the transmit processor by ψ before the respective selected transmit beamforming weight is applied thereto, the transmit processors having a cyclic prefix length of $\Delta\psi$.

[0022] Advantageously, a processor to determine a power-delay-DOA profile estimate for channel $h(n;k)$ is provided and, based on the profile, determine: the length, $\Delta\psi$ cyclic prefix to be added by the transmit processors; the delay ψ; and the transmit beamforming weights.

[0023] Conveniently, a processor is provided to estimate a downlink channel covariance matrix (DCCM) from the

uplink channel covariance matrix (UCCM) to construct transmit beamforming weights.

[0024] Preferably, the base station further comprises a first processor to determine a power-delay-DOA profile estimate for channel $h(n;k)$; and, based on the profile, determine: the length, $\Delta\psi$, of the cyclic prefix to be added by the transmit processors; the delay ψ; and the transmit beamforming weights; and a second processor to estimate a downlink channel covariance matrix (DCCM) from the uplink channel covariance matrix (UCCM) to construct transmit beamforming weights.

[0025] Conveniently, the transmit and receive processors are selected from the group consisting of: OFDM, CDMA and TDMA processors.

[0026] Advantageously, the communications system comprises the base station and a mobile terminal having a single receive antenna, a receive processor to produce an output signal and a space-time decoder to decode the output signal.

[0027] A further aspect of the present invention provides a method of achieving combined beamforming and transmit diversity for frequency selective fading channels in a communication system having a base station with multiple transmit antennae and a mobile terminal with a single receive antenna, the method comprising the steps of: providing a signal to be transmitted $s(n)$; space-time encoding a signal to be transmitted $s(n)$ to produce at least two separate signals $s_1(n)$,$s_2(n)$, each on a respective output; delaying one of the space-time encoded output signals by $\Delta\tau$; applying respective selected transmit beamforming weights to the delayed and undelayed signals; feeding the respective weighted signals to a signal combiner to perform a summing function of the signals and produce a signal for transmission; feeding the summed signal to each of the multiple transmit antennae for transmission; transmitting the summed signals over the physical channel $h(k)$ with two time-delayed rays $h_1(k)$, $h_2(k)$; receiving the major components of the transmitted signals at a single receive antenna at substantially the same time; and space-time decoding the received signal.

[0028] Preferably, the beamforming weights are chosen such that the delayed signal only goes through one ray $h_1(k)$ between the base station multiple transmit antennae and the receive antenna, whilst the undelayed signal only goes through another ray $h_2(k)$ between the base station multiple transmit antennae and the receive antenna.

[0029] Conveniently, the delay $\Delta\tau$ is derived from downlink channel information.

[0030] A further aspect of the present invention provides a base station with multiple transmit antennae for communicating with a mobile terminal having a single receive antenna over physical channel $h(k)$ having two time-delayed rays $h_1(k)$, $h_2(k)$, the base station comprising:

a space-time encoder having an input of a signal to be transmitted and at least two outputs each producing a separate signal; at least two transmit beamformers each receiving an output from the space-time encoder and applying a transmit beamforming weight thereto; a signal combiner receiving signals from the beamformers and operable to perform a summing function of the signals from the beamformers and produce a signal for transmission by each of the multiple transmit antennae, wherein a delay of $\Delta\tau$ is interposed between the space-time encoder and one of the beamformers such that the major components of the transmitted signals are received at a single receive antenna at substantially the same time.

[0031] Preferably, the communications system comprises the base station and a mobile terminal having a single receive antenna and a space-time decoder to decode the received signal.

[0032] One aim of the present invention is to seek to achieve, at the mobile terminal, diversity gain, beamforming gain as well as delay spread reduction simultaneously by using a base station with a multiple antenna array.

[0033] The advantages of the embodiments of the present invention are as follows:

- Beamforming gain and transmit diversity are achieved simultaneously;
- Based on power-delay-DOA profile, delay spread is reduced adaptively.
    - In two-ray environment, a frequency selective fading channel is transferred into a flat fading channel, yet the path diversity gain is maintained.
    - In hilly terrain (HT) environment, we can transfer a long delay spread channel into a short delay spread channel, yet still maintain the path diversity gain.
- With delay spread reduction and combined beamforming and transmit diversity, the invented systems provide high spectrum efficiency, yet consumes less transmission power.
- The invented systems also employ adaptive modulation to further improve the spectrum efficiency based on the diversity order and channel conditions.
- The mobile terminal is usually limited by physical size and battery power. The invented systems put the complicated processing at the base station, rather at the mobile terminal. Thus the mobile terminal complexity is reduced.
- The invented systems are well applicable for the applications which require high data rate for downlink transmission.

These applications include, for example, high speed downlink packet access (HSDPA) in 3rd generation partnership project (3GPP), wireless internet, and wireless multimedia communications.

[0034] In order that the present invention may be more readily understood, embodiments thereof will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 (*Prior Art*) is a schematic diagram illustrating Alamouti's permutation transmit diversity method;

Figure 2 is a schematic diagram illustrating a method embodying the present invention using transmit diversity with pre-equalization for frequency selective fading channels;

Figure 3 *(Prior Art)* is a schematic diagram illustrating orthogonal frequency division multiplexing (OFDM) with transmit diversity at: (a) a transmitter; and (b) a receiver;

Figure 4 *(Prior Art)* is a schematic diagram illustrating OFDM combined beamforming and transmit diversity for flat fading channels;

Figure 5 is a schematic diagram illustrating a method embodying the present invention using OFDM with combined beamforming and transmit diversity at: (a) a transmitter; and (b) a receiver;

Figure 6 is a schematic diagram illustrating a method embodying the present invention using combined beamforming and transmit diversity for two ray (TR) frequency selective fading channels at (a) a transmitter; and (b) a receiver;

Figure 7 is a schematic diagram illustrating a method embodying the present invention using OFDM with combined beamforming and transmit diversity for two ray (TR) models at: (a) a transmitter; and (b) a receiver;

Figure 8 is a schematic diagram illustrating a method embodying the present invention using OFDM with combined beamforming and transmit diversity for hilly-terrain (HR) models at (a) a transmitter; and (b) a receiver; and

Figure 9 is a schematic diagram illustrating a method embodying the present invention using OFDM with combined beamforming, transmit diversity and adaptive delay spread reduction: at (a) a transmitter; and (b) a receiver.

DETAILED DESCRIPTION OF THE INVENTION

[0035] The present invention revolves around the use of multiple antennas at the base station to improve the downlink performance of a wireless communication system. Downlink beamforming is effective in limiting interference pollution, which is of critical importance especially in multimedia communications. Transmit diversity is a powerful technique when receive diversity is impractical, especially for mobile terminals with size and/or power limitations. It can also be used to further improve downlink performance even though receive diversity is available.

[0036] In a multipath propagation environment, a receiver acquires several time-delayed, amplitude-scaled and direction of arrival (DOA) dependent versions of a transmitted signal. When the maximum time delay between the first-arrived and last-arrived versions of a signal along the various paths is smaller than the symbol interval, these paths are not resolvable in the time domain. However, these paths are resolvable in the spatial domain as they may come from different DOAs. Since each path may experience independent fading, using a beamforming antenna array, one obtains several independent channels, to which transmit diversity is applicable.

[0037] When the maximum relative delay is greater than the symbol interval, a frequency selective fading channel is observed. Frequency selectivity is beneficial for achieving diversity, however, it also yields inter-symbol interference (ISI) which needs to be suppressed at the receiver. This phenomenon becomes more and more prevalent as the data transmission rate increases. One way to suppress ISI is to use equalization at the receiver. The performance of an equalizer, however, depends on the frequency responses of the wireless channels. Specifically, when the channel's frequency responses have deep nulls in a certain frequency band, the equalization output yields noise enhancement, the effect of which can degrade the diversity gain obtained by the frequency selectivity. On the other hand, An adaptive equalizer often promotes error propagation problems when decision-directed symbols are used as reference signals, and the complexity of the equalizer is further complicated if the delay spread is large.

[0038] Another method of reducing ISI is to reduce the delay spread using adaptive antennas at the base station. For example, if the base station knows the direction-of-arrival (DOA) information of each delayed version of the received signal, it can then form a beam to one path whilst arranging for nulls or small antenna gains at the DOAs of the other paths. In this manner, the mobile terminal only receives one path of each transmitted signal. This method, though

simple in signal detection, sacrifices the diversity gain since use is only being made of one path.

[0039] Compared to receive diversity, transmit diversity has received greater attention during the past decade. Delay diversity as disclosed in A. Wittneben, "A new bandwidth efficient transmit antenna modulation diversity scheme for linear digital modulation", Proc. Of ICC'93, pp. 1630-1634, 1993, is one early transmit diversity technique using multiple transmit antennas. This method transforms a flat fading channel into a frequency selective fading channel making use of frequency diversity. An equalizer is provided at the mobile terminal in order to compensate for the artificially induced ISI. The performance of the equalizer depends on the frequency property of the channels. Further, an adaptive equalizer often promotes error propagation problems when decision-directed symbols are used as reference signals. In fact, it is shown in Y.C. Liang, Y. Li and K.J.R. Liu, "Feasibility of transmit diversity for IS-136 TDMA systems", Proc. Of VTC '98, pp. 2321-2324, 1998, that when the maximum Doppler frequency is over 40 Hz, this diversity method is even worse than that without diversity. In S.M. Alamouti, "A simple transmit diversity technique for wireless communications", IEEE Journal of Selected Areas in Communications, Vol.16, No.8, pp.1451-1458, October 1998, Alamouti proposed a permutation diversity method, whose performance is similar to maximal-ratio combining (MRC) receive diversity. This method only requires a simple receiver structure. More general transmit diversity methods are referred to as space-time coding methods as disclosed in V. Tarokh, N. Seshadri and A.R. Calderbank, "Space-time codes for high data rate wireless communication: Performance analysis and code construction", IEEE trans. On Information Theory, vol. 44, No. 3, pp. 744-765, March 1998. Space-time codes include space-time trellis codes (STTC) and space-time block codes (STBC). In fact, permutation diversity is the simplest class of STBC.

[0040] Figure 1 illustrating Alamouti's permutation diversity method shows the permutation diversity method with two transmit antennas 1, 2 equipped at the base station (BS). The signal $s(n)$ to be transmitted is first coded in a space-time coding module 3 The space-time coding module 3 works in the following way. It has one input port and two output ports. The input port accepts the transmitted sequence, s(0), s(1), ... The two output ports provide, in response, respective output signals $s_1(t)$ and $s_2(t)$ at time instants $t=n$ and $t=n+1$, where n is an even integer, as follows.

	$t=n$	$t=n+1$
$s_1(t)$	$s(n)/\sqrt{2}$	$s^*(n+1)/\sqrt{2}$
$s_2(t)$	$s(n+1)/\sqrt{2}$	$-s^*(n)/\sqrt{2}$

[0041] At a single receive antenna 4 at the mobile terminal the signals received at time instants $t=n$ and $t=n+1$ are given by

$$x(n) = \alpha_1 s_1(n) + \alpha_2 s_2(n) + w(n) \tag{1}$$

$$x(n+1) = \alpha_1 s_1(n+1)+\alpha_2 s_2(n+1)+w(n+1) \tag{2}$$

where α_1 and α_2 are the respective channel responses from the two transmit antennas 1, 2 to the receiver antenna 4, respectively; $w(n)$ is additive white Gaussian noise (AWGN).

[0042] The received signal is subsequently decoded by the space-time decoding module as follows. Specifically, equations (1) and (2) can be written in matrix forms:

$$\begin{bmatrix} x(n) \\ x(n+1) \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} s(n) & s(n+1) \\ s^*(n+1) & -s^*(n) \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix} + \begin{bmatrix} w(n) \\ w(n+1) \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} x(n) \\ x^*(n+1) \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} \alpha_1 & \alpha_2 \\ -\alpha_2^* & \alpha_1^* \end{bmatrix} \begin{bmatrix} s(n) \\ s(n+1) \end{bmatrix} + \begin{bmatrix} w(n) \\ w^*(n+1) \end{bmatrix} \tag{4}$$

[0043] Therefore, channel coefficients can be estimated via equation (3) using training symbols; while equation (4) can be used for signal estimation/detection. This signal detection method is also called permutation decoding.

[0044] It is pointed out that, as opposed to delay diversity techniques which require a complicated equalizer at the receiver, the channel estimation and signal detection for permutation diversity involves very simple numerical operations. Also, compared to a one-transmitter/two-receiver receive diversity technique, even though the permutation diversity method has a 3 dB performance loss, it achieves the same order of diversity gain as receive diversity techniques using a maximal ratio combining (MRC) approach.

[0045] Permutation diversity can be extended to space-time block codes (STBC) and space-time trellis codes (STTC). All these codes achieve transmit diversity for flat fading environment.

[0046] One example of the invention applies Alamouti's diversity method to frequency selective fading channels. When the delay spread is greater than the symbol interval, frequency selective fading channels are observed. Figure 2 illustrates the system model applying Alamouti's diversity method to frequency selective fading channels. The transmitted signal, $s(n)$, is first coded using Alamouti's codes in the coding module 3, with the two branch outputs as $s_1(n)$ and $s_2(n)$. $s_1(n)$ and $s_2(n)$ are then passed into two pre-equalizers, 6, 7 having functions $g_1(k)$ and $g_2(k)$, to produce two output sequences $y_1(n)$ and $y_2(n)$. $y_1(n)$ and $y_2(n)$ are finally modulated and up-converted as RF signals, which are sent out through the transmit antennas 1, 2 as physical channels $h_1(k)$ and $h_2(k)$.

[0047] The functions $g_1(k)$ and $g_2(k)$ of the pre-equalizers 6,7 are used to pre-equalize the two physical channels, $h_1(k)$ and $h_2(k)$, respectively. By designing the pre-equalizers with zero-forcing criterion, the overall channel responses, $g_1(k) * h_1(k)$ and $g_2(k) * h_2(k)$, are now flat fading channels, with which Alamouti's coding/decoding method can be used. Here, " * " denotes a convolution operation.

[0048] In order to design the pre-equalizers 6,7, the real channel coefficients, $h_1(k)$ and $h_2(k)$, should be known at the base station/transmit antennas 1, 2. This can be done in two ways. For time-division duplex (TDD) systems, downlink channel coefficients are the same as uplink channel coefficients, which are derivable from the uplink using training symbols or blind techniques (up to a constant scaler). For frequency-division duplex (FDD) systems, the base station sends a set of training symbols to the mobile terminal, which then estimates and feeds back the downlink channel information to the base station.

[0049] The above methods are also applicable for other space-time codes.

[0050] Orthogonal frequency division multiplexing (OFDM) is a known and effective method of combatting the large delay spread problem. The combination of OFDM with a transmit diversity method not only suppresses large delay spread, but also achieves transmit diversity gain. Figure 3 shows a prior art OFDM system with two-antenna transmit diversity as described in Y. Li, N. Seshadri and S. Ariyavisitakul, "Channel estimation for OFDM systems with transmitter diversity in mobile wireless channels", IEEE Journal of Selected Areas in Communications, vol. 17, No. 3, pp. 461-471, March 1999. The signal to be transmitted, $S(n;k)$, is first coded using space-time codes in coding module 3, yielding two branch outputs as $S_1(n;k)$ and $S_2(n;k)$. $S_1(n;k)$ and $S_2(n;k)$ are then passed into respective normal OFDM transmit processors 8, 9, whose outputs are finally modulated and up-converted as RF signals, which are sent out through transmit antennas 1, 2.

[0051] At the single antenna receiver 4 at the mobile station, the received signal is passed into a normal OFDM receive processor 10, followed by a space-time decoder module 5. Specifically, the fast Fourier transform (FFT) output becomes

$$X(n;k) = H_1(n;k)S_1(n;k) + H_2(n;k)S_2(n;k) + W(n;k) \tag{5}$$

$$X(n;k+1) = H_1(n;k+1)S_1(n;k+1) + H_2(n;k+1)S_2(n;k+1) + W(n;k+1) \tag{6}$$

[0052] In (5) and (6), $H_1(n;k)$ and $H_2(n;k)$ are, respectively, the Fourier transforms of the channel impulse responses, $h_1(n;k)$ between transmit antenna 1 and receive antenna 4, and $h_2(n;k)$ between transmit antenna 2 and receive antenna 4; $W(n;k)$ is the FFT output of the additive noise, $w(n;k)$, received at the receive antenna 4.

[0053] Permutation decoding methods can be easily applied if $S_1(n;l)$ and $S_2(n;l)$ at time instants $l=k$ and $l=k+1$, where k is an even integer, are chosen as follows:

	$l=k$	$l=k+1$
$S_1(n;l)$	$S(n;k)\,\sqrt{2}$	$S^*(n;k+1)/\sqrt{2}$
$S_2(n;l)$	$S(n;k+1)\,/\,\sqrt{2}$	$-S^*(n;k)\,/\,\sqrt{2}$

Prior Art: Combined beamforming and transmit diversity for flat fading channels.

[0054] The above three methods (Alamouti's permutation diversity method, a diversity method applied to frequency selective fading channels and OFDM with transmit diversity) achieve transmit diversity gain for flat fading channels, or frequency selective fading channels. The transmit antennas belong to diversity antennas, i.e., the antenna spacing is large, e.g., ten times wavelength, typically.

[0055] Figure 4 shows a known system combining beamforming and transmit diversity for flat fading channels as disclosed in R. Negi, A.M. Tehrani and J. Cioffi, "Adaptive antennas for space-time coding over block invariant multipath fading channels", Proc. of IEEE VTC, pp. 70-74, 1999. The signal to be transmitted, $s(n)$, is first coded using a space-time coder module 3, yielding two branch outputs as $s_1(n)$ and $s_2(n)$. $s_1(n)$ and $s_2(n)$ are then passed into two transmit beamformers 11,12, w_1 and w_2, respectively, followed by a signal combiner 13 which performs a simple summing function of the two inputs to producing a signal $x(n)$ for transmission which, in vector form, is as follows:

$$x(n) = w_1^H s_1(n) + w_2^H s_2(n) \tag{7}$$

[0056] To obtain spatial selectivity, the antenna spacing, d, is set to be small, e.g., half wavelength, and the number of transmit antennas 1A, 1B, 2, M, is greater than two. This is a beamforming antenna array, instead of a diversity antenna array. Suppose the physical channel consists of L spatially separated paths, whose fading coefficients and DOAs are denoted as $(\alpha_k(t),\theta_k)$, for $k = 1,\cdots,L$. If the maximum time delay relative to the first arrived path is smaller than the symbol interval, a flat fading channel is observed, and the instantaneous channel response, $h_d(t)$, can be expressed as follows:

$$h_d(t) = \sum_{k=1}^{L} \alpha_k(t) a_d(\theta_k) \tag{8}$$

where $a_d(\theta_k)$ is the downlink steering vector at DOA θ_k. The received signal, $y(n)$, at the mobile terminal is given by

$$y(n) = w_1^H h_d(t) s_1(n) + w_2^H h_d(t) s_2(n) + w(n) \tag{9}$$

[0057] By denoting $\beta_1(t)=w_1^H h_d(t)$, $\beta_2(t)=w_2^H h_d(t)$, the transmit beamforming weights can be estimated by maximizing the cost function:

$$J = E|\beta_1(t)|^2 + E|\beta_2(t)|^2 \tag{10}$$

$$\text{s.t. } E[\beta_1(t)\beta_2^*(t)] = 0 \tag{11}$$

[0058] Maximum average signal to noise ratio (SNR) is obtained by maximising (10); while condition (11) guarantees that $\beta_1(t)$ and $\beta_2(t)$ are statistically uncorrelated, thus maximum diversity gain can be achieved.

[0059] Comparing (9) with (1), with the aid of downlink beamforming, two statistical uncorrelated fading channels, $\beta_1(t)$ and $\beta_2(t)$ have been artificially generated, with which space-time decoding can be used to recover the transmitted signal, $s(n)$. For Alamouti's diversity method, permutation decoding is applied.

[0060] The optimal transmit beamforming weight vectors are the eigenvectors corresponding to the two largest eigenvalues of the downlink channel covariance matrix (DCCM):

$$R_d = E\left[h_d(t)h_d^H(t)\right] \tag{12}$$

where the expectation is conducted over all fading coefficients. Suppose all paths have the same average power, or $E|\alpha_k(t)|^2 = 1/L$, the DCCM is given by

$$R_d = \frac{1}{L}\sum_{k=1}^{L} a_d(\theta_k)a_d^H(\theta_k) \tag{13}$$

[0061] For TDD, DCCM is the same as uplink channel covariance matrix (UCCM). For FDD, there are two ways to estimate the DCCM, both of which are based on the fact that uplink and downlink signals go through the same DOAs. The first method estimates the DOAs of all paths from the received uplink signals first, then constructs the downlink steering vectors, $a_d(\theta_k)$'s, and further DCCM R_d via equation (13). The second method estimates DCCM from UCCM directly via frequency calibration processing as disclosed in Y-C. Liang and F. Chin, "Downlink beamforming methods for capacity enhancement in wireless communication systems", Singapore Patent Application No. 9904733.4. This method does not involve DOA estimation and its associates and is therefore simple to implement.

[0062] This system achieves diversity gain and beamforming gain simultaneously for flat fading environment but it is desirable to extend that system into a frequency selective fading environment.

[0063] For mobile wireless communications without beamforming, the two ray (TR) model, typical urban (TU) model, and hilly terrain (HT) model are three commonly used power-delay profiles. When downlink beamforming is added, a power-delay-DOA profile should be considered. In picocell, microcell, and macrocell with TU model, there is less correlation between path delays and the DOAs. However, in macrocell with TR and HR models, the path delays are usually statistically dependent on the DOAs. We will show that for different environments, there exist different schemes to achieve combined beamforming and transmit diversity gains, as well as maximum spectrum efficiency.

[0064] Another example of the invention utilises OFDM to obtain combined beamforming and transmit diversity.

[0065] Combined beamforming and transmit diversity can be achieved by using OFDM for frequency selective fading channels. Figure 5 shows the OFDM system with combined beamforming and transmit diversity. Even though OFDM is selected as one example to show how the delay spread can be reduced, while yet maintaining beamforming and transmit diversity gain, other examples being other multi-carrier modulation schemes, such as MC-CDMA, MC-DS-CDMA and single carrier systems with cyclic prefix.

[0066] The transmitted signal at the *k*th tone of the *n*th block, $S(n;k)$, is first coded at the base station using space-time codes in coding module 3, yielding two branch outputs, $S_1(n;k)$ and $S_2(n;k)$. $S_1(n;k)$ and $S_2(n;k)$ are passed into respective normal OFDM transmit processors 8,9, followed by two transmit beamformers, 10,11, (w_1 and w_2) respectively. The beamforming outputs are finally combined in a combiner 13, and transmitted out through the transmit antennas 1A, 1B, 2 of the base station antenna array.

[0067] With the base station antenna array 1A, 1B, 2, the complex baseband representation of a wireless channel impulse response can be described as the following vector form

$$h_d(t;\tau) = \sum_m \sum_l \gamma_{m,l}(t)a_d(\theta_{m,l})\delta(\tau - \tau_m) \tag{14}$$

where τ_m is the delay of the *m*th path resolved in time, $\gamma_{m,l}(t)$ and $a_d(\theta_{m,l})$ are the complex amplitude and downlink steering vector corresponding to lth DOA of the *m*th delay path. Because of the motion of the vehicular, $\gamma_{m,l}(t)$'s are wide-sense stationary (WSS) narrow band complex Gaussian processes, which are zero-mean and statistically independent for different *m*'s, or *l*'s. Suppose all $\gamma_{m,l}(t)$'s have the same normalized correlation function, $r(t)$ ($r(0)=1$), but possibly different average power, σ_{ml}^2, then

$$E\left[\gamma_{m,l}(t+\Delta t)\gamma^{*}_{m,l}(t)\right]=\sigma^{2}_{m,l}r(\Delta t) \tag{15}$$

[0068] The Fourier transform (FT) of $h(t;\tau)$ at time instant t is given by

$$H_d(t;f)=\int_{-\infty}^{\infty}h_d(t;\tau)e^{-j2\pi f\tau}d\tau=\sum_m\sum_l\gamma_{m,l}(t)a_d(\theta_{m,l})e^{-j2\pi f\tau_m} \tag{16}$$

[0069] For an OFDM system with block length T_b and tone spacing f_t, the discrete value of $H(t;f)$ is given by

$$H_d[n;k]\triangleq H_d(nT_b;kf_t)=\sum_m\sum_l\gamma_{m,l}(nT_s)a_d(\theta_{m,l})e^{-j2\pi kf_t\tau_m} \tag{17}$$

thus the correlation function matrix of the frequency response for different times and frequencies is given by

$$r_d[\Delta n;\Delta k]=E\left[H_d[n+\Delta n;k+\Delta k]H_d^H[n;k]\right]=r(\Delta nT_b)\sum_m e^{-j2\pi\Delta kf_t\tau_m}R_{d,m} \tag{18}$$

where

$$R_{d,m}=\sum_l\sigma^2_{m,l}a_d(\theta_{m,l})a_d^H(\theta_{m,l})$$

is the downlink channel covariance matrix corresponding to the mth delay path. Note for $\Delta n = 0$ and $\Delta k = 0$,

$$r_d[0;0]=\sum_m\sum_l\sigma^2_{m,l}a_d(\theta_{m,l})a_d^H(\theta_{m,l})\triangleq R_d \tag{19}$$

[0070] At the mobile terminal single antenna 4, the received signals are first passed into normal OFDM receive processor 10, followed by a permutation decoder 5. Within the normal OFDM receive processor, the FFT output becomes

$$X[n;k] = w_1^H H_d[n;k]S_1[n;k] + w_2^H H_d[n;k]S_2[n;k] + W[n;k] \tag{20}$$

$$X[n;k+1] = w_1^H H_d[n;k+1]S_1[n;k+1]+w_2^H H_d[n;k+1]S_2[n;k+1]+W[n;k+1] \quad (21)$$

where $W[n;K]$ is zero mean AWGN.

[0071] By denoting $\beta_1 = w_1^H H_d[n;k]$, $\beta_2 = w_2^H H_d[n;k]$, the beamforming weights can be estimated by maximizing the cost function:

$$J = E|\beta_1|^2 + E|\beta_2|^2 \quad (22)$$

$$\text{s.t.} \quad E[\beta_1\beta_2^*] = 0 \quad (23)$$

[0072] Again, maximum average SNR is obtained through maximizing equation (22); while condition (23) guarantees that β_1 and β_2 are statistically uncorrelated, thus maximum diversity gain can be achieved.

[0073] The optimal transmit beamforming weight vectors are the eigenvectors corresponding to the two largest eigenvalues of downlink channel covariance matrix (DCCM) R_d.

$$R_d = E[H_d[n;k]H_d^H[n;k]] \quad (24)$$

[0074] Comparing equations (20) and (21) with equations (5) and (6), with the aid of downlink beamforming, two uncorrelated fading channels are generated, with which the space-time decoding can be used to recover the transmitted signal. Permutation decoding method can be applied if $S_1(n;k)$ and $S_2(n;k)$ are chosen as follows.

	$t=k$	$t=k+1$
$S_1(n;t)$	$s(n;k)/\sqrt{2}$	$s^*(n;k+1)/\sqrt{2}$
$S_2(n;t)$	$s(n;k+1)/\sqrt{2}$	$-s^*(n;k)/\sqrt{2}$

[0075] A frequency calibration method for DCCM estimation for OFDM.

[0076] In order to generate the downlink beamforming weights, it is first necessary to construct the DCCM. A frequency calibration (FC) method disclosed in Y-C. Liang and F. Chin, "Downlink beamforming methods for capacity enhancement in wireless communication systems", Singapore Patent Application No. 9904733.4 is applied.

[0077] Using a similar method, we can show that the correlation function matrix of the uplink frequency response for different times and frequencies is given by

$$r_u[\Delta n;\Delta k] = E[H_u[n+\Delta n;k+\Delta k]H_u^H[n;k]] = r(\Delta n T_b)\sum_m e^{-j2\pi\Delta k f_s \tau_m} R_{u,m} \quad (25)$$

where

$$R_{u,m} = \sum_l \sigma_{m,l}^2 a_u(\theta_{m,l})a_u^H(\theta_{m,l})$$

is the uplink channel covariance matrix corresponding to the mth delay path. Note for $\Delta n = 0$ and $\Delta k = 0$,

$$r_u[0;0] = \sum_m \sum_l \sigma_{m,l}^2 a_u(\theta_{m,l}) a_u^H(\theta_{m,l}) \underline{\underline{\Delta}} R_u \tag{26}$$

[0078] Comparing equations (19) and (26), the FC method devised in Y-C. Liang and F. Chin, "Downlink beamforming methods for capacity enhancement in wireless communication systems", Singapore Patent Application No. 9904733.4 is used to estimate the DCCM from UCCM.

[0079] This system provides diversity gain and beamforming gain for OFDM systems. In this system, the length of cyclic prefix is determined by the maximum physical time delay, and is the same as that in a normal OFDM system. Thus it is readily applicable to the environment in which the DOA is statistically independent of the time delay.

[0080] When the DOA of a path is statistically related to the path delay, e.g., in TR and HR environments, one can not only achieve beamforming gain and diversity gain simultaneously, but also reduce the cyclic prefix, thus obtaining improved spectrum efficiency.

[0081] A further example of the present invention utilises combined beamforming and transmit diversity for frequency selective fading channels for two ray (TR) models.

[0082] Suppose the physical channel follows a TR model. With the base station antenna array, the complex baseband representation of a wireless channel impulse response can be described as the following vector form

$$h_d(t;\tau) = \sum_{m=1}^{2} h_{d,m}(t)\delta(\tau - \tau_m) \tag{27}$$

with

$$h_{d,m}(t) = \sum_l \gamma_{m,l}(t) a_d(\theta_{m,l}) \tag{28}$$

where τ_m is the delay of the mth path resolved in time, $\gamma_{m,l}(t)$and $a_d(\theta_{m,l})$ are the complex amplitude and downlink steering vector corresponding to lth DOA of the mth delay path. Because of the motion of the vehicular, $\gamma_{m,l}(t)$'s are wide-sense stationary (WSS) narrow band complex Gaussian processes, which are zero-mean and statistically independent for different m's, or l's. Suppose all $\gamma_{m,l}(t)$'s have the same normalized correlation function, $r(t)$ ($r(0) = 1$), but possibly different average power, $\sigma_{m,l}^2$, then

$$E\left[\gamma_{m,l}(t+\Delta t)\gamma_{m,l}^*(t)\right] = \sigma_{m,l}^2 r(\Delta t) \tag{29}$$

[0083] ISI exists when $\Delta\tau = \tau_2 - \tau_1$ is greater than the symbol interval. With combined beamforming and diversity technique, if the two rays are spatially separated, it is possible to transfer a frequency selective fading channel into a flat fading channel, yet maintain the transmit diversity.

[0084] Figure 6 shows a communication system with combined beamforming and transmit diversity for two-ray frequency selective fading channels. The signal to be transmitted, $s(n)$, is first coded in a coding module 3 using space-time codes, with the two branch outputs as $s_1(n)$ and $s_2(n)$. $s_1(n)$ is then fed through a delay 14 to delay $s(n)$ by $\Delta\tau$, yielding $x_1(n)$, which is further passed to transmit beamformer 11, (w_1). The second branch output $s_2(n)$ is directly passed to the other transmit beamformer 12, (w_2). The beamforming outputs are then combined in combiner 13 and sent by transmit antennas 1A, 1B, 2, yielding the transmitted signal as follows:

$$x(n) = w_1^H x_1(n) + w_2^H s_2(n) \quad (30)$$

[0085] The received signal, *y(n)*, at the mobile terminal single antenna 4 is given by

$$\begin{aligned} y(n) &= w_1^H h_{d,1} x_1(n) + w_1^H h_{d,2} x_1(n - \Delta\tau) \\ &+ w_2^H h_{d,1} s_2(n) + w_2^H h_{d,2} s_2(n-\Delta\tau) + w(n) \end{aligned} \quad (31)$$

[0086] Denoting $z(n) = y(n+\Delta\tau)$, and considering the pre-alignment of the two transmitted signals, gives:

$$\begin{aligned} z(n) &= w_1^H h_{d,1} s_1(n) + w_1^H h_{d,2} s_1(n-\Delta\tau) \\ &+ w_2^H h_{d,1} s_2(n + \Delta\tau) + w_2^H h_{d,2} s_2(n) + w(n + \Delta\tau) \end{aligned} \quad (32)$$

[0087] The beamforming weights are chosen such that the first branch output, $s_1(n)$, just goes through the first path, $h_{d,1}$between the base station antenna array and the receive antenna 4; while the second branch output, $s_2(n)$, just goes through the second path, $h_{d,2}$ between the base station antenna array and the receive antenna 4. Mathematically,

$$\begin{cases} w_1^H h_{d,2} = 0 \\ \left| w_1^H h_{d,1} \right|^2 = \max \end{cases}$$

and

$$\begin{cases} w_2^H h_{d,1} = 0 \\ \left| w_2^H h_{d,2} \right|^2 = \max \end{cases}$$

[0088] In this case the ISI terms are suppressed completely, and *z(n)* can be written as

$$z(n) = w_1^H h_{d,1} s_1(n) + w_2^H h_{d,2} s_2(n) + w(n + \Delta\tau) \quad (33)$$

[0089] Thus the frequency selective fading channel is now transformed into a flat fading channel, with which the transmit diversity method can be applied.

[0090] Conveniently, the transmit beamforming weights can be chosen by maximizing the average transmit SINR functions:

$$J_1(w_1) = \frac{w_1^H R_{d,1} w_1}{w_1^H R_{d,2} w_1} \text{ and } J_2(w_1) = \frac{w_2^H R_{d,2} w_2}{w_2^H R_{d,1} w_2}$$

where

$$R_{d,m} = E\left[h_{d,m}(t)h_{d,m}^H(t)\right] = \sum_l \sigma_{m,l}^2 a_d(\theta_{m,l}) a_d^H(\theta_{m,l}) \quad (34)$$

is the downlink channel covariance matrix of the mth path.

[0091] Preferably, the transmit beamforming weights can be chosen by maximizing the average receive SINR at the mobile receiver, i.e.,

$$J = \frac{w_1^H R_{d,1} w_1 + w_2^H R_{d,2} w_2}{w_1^H R_{d,2} w_1 + w_2^H R_{d,1} w_2 + \sigma_n^2}, \quad (35)$$

[0092] Advantageously, the transmit beamforming weights, w_m, can be chosen as the principal eigenvector of $R_{d,m}$.

[0093] Again, the frequency calibration method disclosed in Y-C. Liang and F. Chin, "Downlink beamforming methods for capacity enhancement in wireless communication systems", Singapore Patent Application No. 9904733.4 is used to estimate the DCCM from UCCM directly.

[0094] The above method for achieving combined beamforming and transmit diversity gain is called pre-alignment (PAL) method. The purpose of delaying $s_1(n)$ by $\Delta\tau$ is to make sure that the major components of the two sequences, $s_1(n)$ and $s_2(n)$ arrive at the receiver at the same time. Therefore, the delay spread has been reduced to zero. On the other hand, beamforming is used to minimize the ISI effect as well as to artificially generate two uncorrelated channels, with which the transmit diversity gain is achieved.

[0095] The PAL method requires the delay information, $\Delta\tau$, which is embedded in the downlink power-delay-DOA (PDD) profile. Even though the PDD profile is time varying, it changes slowly in time. Also, downlink PDD profile is almost the same as uplink PDD profile, which can be estimated from received uplink signals.

[0096] The PAL method can also be applied to the systems whose number of rays is grater than 2. In this case, it requires more than 2 branches of space-time coding outputs, and each output except the first one corresponds to one delay.

[0097] If the number of space-time coding outputs is fixed, say 2, the two major rays can be selected in order to generate the delay, $\Delta\tau$, and the transmit beamforming weights. The direct application of this system is to reduce inter-fmger-interference in CDMA as the total number of fingers is reduced.

[0098] Conventionally, when the physical channel h(k) consists of multiple rays with two major rays $h_1(k)$, $h_2(k)$ delayed by $\Delta\tau$, the beamforming weights are chosen such that the delayed signal only goes through one ray $h_1(k)$ between the base station multiple transmit antennae and the receive antenna, whilst the undelayed signal only goes through another ray $h_2(k)$ between the base station multiple transmit antennae and the receive antenna.

[0099] Advantageously, when the physical channel h(k) consists of multiple rays with two major rays $h_1(k)$, $h_2(k)$ delayed by $\Delta\tau$, the beamforming weights are chosen such that the average transmit SINR function at the base station is maximized for each ray.

[0100] Preferably, when the physical channel h(k) consists of multiple rays with two major rays $h_1(k)$, $h_2(k)$ delayed by $\Delta\tau$, the beamforming weights are chosen such that the average receive SINR function at the mobile terminal is maximized.

[0101] Another example of the present invention utlises OFDM with combined beamforming and transmit diversity for frequency selective fading channels for two ray (TR) models.

[0102] There is a direct use of delay spread reduction in OFDM. In a typical OFDM system, a cyclic prefix is added in order to remove the ISI and to guarantee the orthogonality between each sub-channel. The length of the cyclic prefix should be greater than the maximum time delay, which can be as large as 40 μs for a mobile wireless communication environment. The adding of the cyclic prefix not only degrades the spectrum efficiency, but also occupies one portion of the transmit power. The spectrum efficiency and power efficiency of the OFDM system can be greatly improved if the cyclic prefix can be reduced while maintaining the same performance.

[0103] Suppose the physical channel follows a TR model with parameters $(\alpha_k,\theta_k,\tau_k)$, k = 1,2 and $\tau_1<\tau_2$. α_k's are statistically independent, zero mean complex Gaussian processes with variance σ_k^2. ISI exists when $\Delta\tau = \tau_2-\tau_1$ is greater than the inverse of bandwidth.

[0104] Figure 7 illustrates an OFDM system with combined beamforming and transmit diversity for TR models embodying the present invention. The transmitted signal at the kth tone of the nth block, $S(n;k)$, is first coded using space-time codes in coding module 3, yielding two branch outputs, $S_1(n;k)$ and $S_2(n;k)$. Both branch outputs $S_1(n;k)$ and $S_2(n;k)$ are passed into respective OFDM transmit processors 8,9 without adding cyclic prefixes. $S_1(n;k)$ is then delayed

in delay 14 by $\Delta\tau$, yielding $X_1(n;k)$, which is further passed to transmit beamformer 11, (w_1). The second branch output $S_2(n;k)$ is directly passed to the other transmit beamformer 12, (w_2). The beamforming outputs are then combined and sent on the base station transmit antenna array 1A, 1B, 2, yielding the transmitted signal as follows:

$$x(n;k) = w_1^H x_1(n;k) + w_2^H s_2(n;k) \quad (36)$$

[0105] At the mobile terminal single antenna 4, the received signals are first passed into a normal OFDM receive processor 10. The beamforming weights are chosen such that the first branch output, $S_1(n;k)$ or its inverse FFT (IFFT), $s_1(n;k)$, just goes through the first path, $h_1(n;k)$ between the base station antenna array and the receive antenna 4; while the second branch output, $S_2(n;k)$ or its inverse FFT (IFFT), $s_2(n;k)$, just goes through the second path, $h_1(n;k)$ between the base station antenna array and the receive antenna 4. Once the transmit beamforming weights are properly chosen, the FFT output of the received signal at the mobile station becomes

$$Z[n;k] = w_1^H H_1[n;k]S_1[n;k] + w_2^H H_2[n;k]S_2[n;k] + W[n;k + \lfloor \Delta\tau f_t \rfloor]$$

(37)

[0106] Comparing equation (37) with equation (5), with the aid of downlink beamforming, two different channels have been artificially created which can be space-time decoded by module 5 to recover the transmitted signal. Further, permutation decoding method can be easily applied if $S_1(n;k)$ and $S_2(n;k)$ are chosen as follows.

	$t=k$	$t=k+1$
$S_1(n;t)$	$s(n;k)/\sqrt{2}$	$s^*(n;k+1)/\sqrt{2}$
$S_2(n;t)$	$s(n;k+1)/\sqrt{2}$	$-s^*(n;k)/\sqrt{2}$

[0107] When PAL is applied to an OFDM system with combined beamforming and transmit diversity for TR models, it is not necessary to add the cyclic prefix. Thus benefiting from the advantages of: transmit diversity; beamforming gain; and increased spectrum efficiency.

[0108] Conveniently, the transmit beamforming weights can be chosen by maximizing the average transmit SINR functions.

[0109] Preferably, the transmit beamforming weights can be chosen by maximizing the average receive SINR at the mobile receiver.

[0110] Advantageously, the transmit beamforming weights, w_m, can be chosen as the principal eigenvector of $R_{d,m}$.

[0111] Again, the frequency calibration method disclosed in Y-C. Liang and F. Chin, "Downlink beamforming methods for capacity enhancement in wireless communication systems", Singapore Patent Application No. 9904733.4 is used to estimate the DCCM from UCCM directly.

[0112] A comparison of the spectrum efficiency and power savings by using this delay spread reduction method will follow.

[0113] A further example of the invention utilises OFDM with combined beamforming and transmit diversity for frequency selective fading channels for hilly terrain (HT) models.

[0114] Even though the maximum time delay can be as large as 40 µs, a wireless channel satisfying HT model can be described by several dominated clustered paths, each of which has a small delay spread. These clustered paths are also spatially separated. For an OFDM with typical HT power-delay profile whose maximum time delay is 20 µs, and maximum delay spread for each clustered path is 2 µs, the minimum length of cyclic prefix is 20µs in order to remove the ISI. However, with the PAL method, the cyclic prefix duration can be reduced to 2 µs .

[0115] Suppose the two clustered paths are delayed by ψ,and for simplicity, assume the delay spread for each clustered path is $\Delta\psi$. The impulse response of the time varying channel can be described as

$$h(t;\tau) = h_1(t;\tau)[u(\tau) - u(\tau - \Delta\psi)] + h_2(t;\tau - \psi)[u(\tau - \psi) - u(\tau - \psi - \Delta\psi)] \quad (38)$$

where $h_1(t;\tau)$ and $h_2(t;\tau)$ correspond to the channel responses of the first and second clustered paths, respectively; and $u(x)$ is a unit step function..

[0116] Figure 8 shows an OFDM system embodying the present invention with combined beamforming and transmit diversity for hilly terrain (HT) model in encoder module 3. The signal to be transmitted at the kth tone of the nth block, $S(n;k)$, is first coded using space-time codes in encoder module 3, yielding two branch outputs, $S_1(n;k)$ and $S_2(n;k)$ which are passed into respective normal OFDM transmit processors 8,9, whose cyclic prefix length is $\Delta\psi$, instead of $\psi + \Delta\psi$. The output from the first branch is then delayed by ψ in delay 15, while the output from the second branch remains unchanged. After that, the signals are passed into respective transmit beamformers 11,12, (w_1 and w_2), respectively. The beamforming outputs are then combined in combiner 13, and transmitted out through the base station transmit antenna array 1A, 1B, 2.

[0117] The beamforming weights are chosen such that the first branch input just goes through the first clustered path, while the second branch input just goes through the second clustered path - i.e. the beamforming weights are chosen such that the first branch output, $s_1(n)$, just goes through the first path, $h_{d,1}$between the base station antenna array and the receive antenna 4; while the second branch output, $s_2(n)$, just goes through the second path, $h_{d,2}$between the base station antenna array and the receive antenna 4. The signals received at the mobile terminal single antenna 4 are first passed into a normal OFDM receive processor 10, followed by a space-time decoding module 5. Within the normal OFDM receive processor 10, the received signal after FFT becomes

$$Z[n;k] = w_1^H H_1[n;k]S_1[n;k] + w_2^H H_2[n;k]S_2[n;k] + W[n;k + \lfloor \psi f_s \rfloor] \quad (39)$$

where $\lfloor x \rfloor$ denotes the maximum integer which is not greater than x. Comparing equation (39) with equation (5), with the aid of downlink beamforming, two different channels have been artificially generated, which are space-time decoded to recover the transmitted signal. Permutation decoding methods can be easily applied if $S_1(n;k)$ and $S_2(n;k)$ are chosen as follows.

	$t=k$	$t=k+1$
$S_1(n;t)$	$s(n;k)/\sqrt{2}$	$s^*(n;k+1)/\sqrt{2}$
$S_2(n;t)$	$s(n;k+1)/\sqrt{2}$	$-s^*(n;k)/\sqrt{2}$

[0118] Conveniently, the transmit beamforming weights can be chosen by maximizing the average transmit SINR functions.

[0119] Preferably, the transmit beamforming weights can be chosen by maximizing the average receive SINR at the mobile receiver.

[0120] Advantageously, the transmit beamforming weights, w_m, can be chosen as the principal eigenvector of $R_{d,m}$.

[0121] As previously mentioned, there follows a comparison the spectrum efficiency of a OFDM system with different cyclic prefix lengths.

[0122] The parameters are Bandwidth B = 800 kHz, maximum time delay = 40. For HT models, the maximum delay spread for each clustered path is 5. To make the tones orthogonal to each other, the symbol duration is N/B, where N is the number of tones in each OFDM symbol. The total block length is the summation of the symbol duration and the additional guard interval, which is 40, 5, and 0 for OFDM without PAL, HT with PAL and TR with PAL, respectively.

[0123] Table I illustrates the uncoded transmit data rate for OFDM systems with different number of tones using QPSK modulation. It is seen that, for a given modulation scheme and with the same number of tones, the transmit data rate can increase to 1.6Mbps for TR environments by using PAL, independent of the N value. For HT with PAL, the spectrum efficiency is also increased as compared with that without PAL.

Table I:

transmit data rate comparison			
	N=128	N=64	N=32
Without PAL	1.28 Mbps	1.07 Mbps	800 kbps
HT with PAL	1.55 Mbps	1.51 Mbps	1.42 Mbps
TR with PAL	1.6 Mbps	1.6 Mbps	1.6 Mbps

[0124] Here follows a comparison of the power savings for OFDM with different lengths of cyclic prefix:

[0125] Due to the adding of a cyclic prefix, the effective $\frac{E_b}{N_o}$ is smaller than the actual transmit $\frac{E_b}{N_o}$. With delay spread reduction, the transmit power is more efficiently used. Table II illustrates the power savings for OFDM systems with delay spread reduction using PAL for different number of tones in each OFDM block, as compared to normal OFDM systems.

Table II:

Power savings			
	N=128	N=64	N=32
HT with PAL	0.84 dB	1.5 dB	2.5 dB
TR with PAL	0.97 dB	1.76 dB	3.0 dB

Beamforming and diversity gain:

[0126] With combined beamforming and diversity gain, it takes less $\frac{E_b}{N_o}$ in order for the system to achieve a given bit-error-rate (BER) requirement. Alternatively, the beamforming and diversity gain can be translated to larger spectrum efficiency using higher modulation scheme such as 128 QAM or 256 QAM.

[0127] A further embodiment of the present invention relates to adaptive delay spread reduction with combined beamforming and diversity gain:

[0128] The previously described embodiments are designed for different environments. In real applications, the power-delay-DOA (PDD) profile may change with respect to time due to the motion of a vehicle, thus the delay spread reduction scheme should follow this variation accordingly in order to achieve maximum spectrum efficiency. Figure 9 shows an OFDM system with combined beamforming, transmit diversity and adaptive delay spread reduction for downlink embodying the present invention. The OFDM system of Figure 9 comprises the system of Figure 8 but supplemented by UCCM estimation and power-delay-DOA profile estimation. Thus, in addition to the functionality provided by the system of Figure 8, this system has the following functionality.

- From uplink signals received at the base station, the time-delay and direction-of-arrival (DOA) information is estimated for each received path, using training sequences or blind techniques. Based on the estimated time-delay and DOA information, uplink power-delay-DOA (PDD) profile, and each clustered path's UCCM are estimated;
- Based on uplink PDD profile, the following parameters are determined: diversity order, time delays for each clustered path, and the maximum delay spread for the clustered paths.
- The uplink PDD profile is used to design the adaptive delay reduction scheme, thus the adaptive cyclic prefix adding scheme;
- Each clustered path's DCCM is estimated from its corresponding UCCM using FC method disclosed in Y-C. Liang and F. Chin "Downlink beamforming methods for capacity enhancement in wireless communication systems", Singapore Patent Application No. 9904733.4, then applied, together with time delay information, for constructing transmit beamforming weights;
- The base station informs the MS the length of added cyclic prefix;
- Adaptive modulation is also used to further improve the spectrum efficiency based on the diversity order/channel condition. Specifically, based on uplink PDD profile, the maximum achievable diversity order is determined. If the achievable diversity order is large, a higher modulation scheme is applied; otherwise, a smaller modulation scheme is applied.

[0129] It should be noted that the number of branch outputs after space-time coding in module 3 can be greater than two, depending on the diversity order to be achieved.

[0130] The above description considers the combined beamforming, transmit diversity and delay spread reduction implemented at the base station. In fact, multiple diversity antennas can be added at the mobile terminal as well to achieve receive diversity. In this case, larger diversity gains can be achieved:

[0131] Even though OFDM is used to show how the delay spread can be reduced, while yet maintaining beamforming and transmit diversity gain, the disclosure in this application can be applied to other multi-carrier modulation schemes, such as MC-CDMA, MC-DS-CDMA and single carrier systems with cyclic prefix.

[0132] In a multiuser environment, the beamforming weights can be generated by considering all users' channel/DOA information; therefore, the disclosure in this application is applicable in different multiple access schemes, such as time-division-multiple-access (TDMA), frequency-division-multiple-access (FDMA), and code-division-multiple-access (CDMA).

"comprising" means "including or consisting of".

[0133] The features disclosed in the foregoing description, or the following claims, or the accompanying drawings, expressed in their specific forms or in terms of a means for performing the disclosed function, or a method or process for attaining the disclosed result, as appropriate, may, separately, or in any combination of such features, be utilised for realising the invention in diverse forms thereof.

Claims

1. A method of achieving transmit diversity gain for frequency selective fading channels in a communication system having a base station with multiple transmit antennae and a mobile terminal with at least a single receive antenna, the method comprising the steps of:

   providing a signal to be transmitted $s(n)$;
   space-time encoding the signal $s(n)$ to produce at least two separate signals $s_1(n),s_2(n)$, each on a respective output;
   feeding each output signal $s_1(n),s_2(n)$ to a zero-forcing pre-equaliser having a respective function $g_1(k)$, $g_2(k)$ to produce an output signal $x_1(n)$, $x_2(n)$;
   feeding the output signal $x_1(n)$, $x_2(n)$ of each pre-equaliser to a transmit antenna;
   transmitting the output signals $x_1(n)$, $x_2(n)$ over respective physical channels $h_1(k)$, $h_2(k)$;
   receiving the output signals $x_1(n)$, $x_2(n)$ at at least a single receive antenna; and space-time decoding the received signals, wherein
   the functions $g_1(k)$, $g_2(k)$ of the zero-forcing pre-equalisers are selected such that the channel responses $g_1(k)^*h_1(s)$, $g_2(k)^*h_2(k)$ of the respective physical channels $h_1(k)$, $h_2(k)$ are flat fading channels.

2. A method according to Claim 1, wherein the communications system is a time-division duplex system and the method includes the further step of deriving the real channel coefficients from uplink channel coefficients for use in selecting the functions $g_1(k)$, $g_2(k)$ of the pre-equalisers.

3. A method according to Claim 2, wherein the step of deriving the real channel coefficients from uplink channel coefficients uses training symbols from the uplink channel.

4. A method according to Claim 2, wherein the step of deriving the real channel coefficients from uplink channel coefficients uses blind techniques.

5. A method according to Claim 1, wherein the communications system is a frequency-division duplex system and the method includes the further step of deriving the real channel coefficients by sending a set of training symbols to the receive antenna of the mobile terminal, the mobile terminal estimating the real channel coefficients and feeding back channel coefficient information to the base station.

6. A base station with multiple transmit antennae for communicating with a mobile terminal having at least a single receive antenna over physical channels $h_1(k)$, $h_2(k)$ the base station comprising:

   a space-time encoder having an input of a signal to be transmitted $s(n)$ and at least two outputs each producing a separate signal $s_1(n),s_2(n)$;
   at least two zero-forcing pre-equalisers, each fed by a respective output signal $s_1(n),s_2(n)$ and having a respective function $g_1(k)$, $g_2(k)$ to produce an output signal $x_1(n)$, $x_2(n)$; and
   at least two transmit antennae, each being fed by the output signal $x_1(n)$, $x_2(n)$ of a respective one of the pre-

equalisers, wherein the functions $g_1(k)$, $g_2(k)$ of the zero-forcing pre-equalisers are selected such that the channel responses $g_1(k)^*h_1(k)$, $g_2(k)^*h_2(k)$ of the respective physical channels $h_1(k)$, $h_2(k)$ are flat fading channels.

7. A communications system comprising the base station of Claim 6 and a mobile terminal having at least a single receive antenna and a space-time decoder to decode the signals received from the base station.

8. A method of achieving combined beamforming and transmit diversity for frequency selective fading channels in a communication system having a base station with multiple transmit antennae and a mobile terminal with at least a single receive antenna, the method comprising the steps of:

providing a signal to be transmitted $S(n;k)$;
space-time encoding the signal $S(n;k)$ to produce at least two separate signals $S_1(n;k)$,$S_2(n;k)$, each on a respective output;
feeding each output signal $S_1(n;k)$,$S_2(n;k)$ to a transmit processor to produce an output signal $X_1(n;k)$, $X_2(n;k)$;
applying respective selected transmit beamforming weights to each output signal $X_1(n;k)$, $X_2(n;k)$;
feeding the respective weighted signals to a signal combiner to perform a summing function of the signals and produce a signal X(n;k) for transmission;
feeding the summed signal X(n;k) to each of the multiple transmit antennae for transmission;
transmitting the signals X(n;k) over physical channel $h(n;k)$;
receiving the received signal Y(n;k) at at least a single receive antenna;
feeding the received signal Y(n;k) to a receive processor to produce an output signal; and
space-time decoding the received signal.

9. A method according to Claim 8, wherein the respective transmit beamforming weights are selected as the eigenvectors corresponding to the two largest eigenvalues of the downlink channel covariance matrix (DCCM) of the physical channels h(n;k).

10. A method according to Claim 8, wherein the physical channel h(n;k) consists of two time-delayed rays, $h_1(n;k)$ and $h_2(n;k)$, with delay $\Delta\tau$, the transmit processors do not add cyclic prefixes and one of the output signals from the transmit processors is delayed by $\Delta\tau$ before the respective selected transmit beamforming weight is applied thereto.

11. A method according to Claim 8, wherein the physical channel h(n;k) consists of two time-delayed rays, $h_1(n;k)$ and $h_2(n;k)$, with delay $\Delta\tau$, the beamforming weights being chosen such that the delayed signal or its inverse fast Fourier transform (IFFT) only goes through one channel $h_1(n;k)$ between the base station multiple transmit antennae and the receive antenna, whilst the undelayed signal or its IFFT only goes through another channel $h_2(n;k)$ between the base station multiple transmit antennae and the receive antenna, thereby creating two different channels which can be space-time decoded to recover the transmitted signal.

12. A method according to Claim 8, wherein the physical channel h(n;k) consists of two time-delayed rays, $h_1(n;k)$ and $h_2(n;k)$, with delay $\Delta\tau$, the beamforming weights being chosen such that the average transmit SINR function at the base station is maximized for each ray.

13. A method according to Claim 8, wherein the physical channel h(n;k) consists of two time-delayed rays, $h_1(n;k)$ and $h_2(n;k)$, with delay $\Delta\tau$, the beamforming weights being chosen such that the average receive SINR function at the mobile terminal is maximized.

14. A method according to Claim 8, wherein the physical channel h(n;k) consists of two time-delayed rays, $h_1(n;k)$ and $h_2(n;k)$, with delay $\Delta\tau$, the beamforming weights for each ray are chosen as the principal eigenvector of the downlink channel covariance matrix (DCCM) corresponding to that ray.

15. A method according to Claim 8, wherein the physical channel h(n;k) consists of two time-delayed clustered rays, $h_1(n;k)$ and $h_2(n;k)$, with delay ψ, and maximum excess delay for the clusters $\Delta\psi$, the transmit processors have a cyclic prefix length of $\Delta\psi$ and one of the output signals from the transmit processors is delayed by ψ before the respective selected transmit beamforming weight is applied thereto.

16. A method according to Claim 15, wherein the beamforming weights are chosen such that the delayed signal or its inverse fast Fourier transform (IFFT) only goes through one channel $h_1(n;k)$ between the base station multiple

transmit antennae and the receive antenna, whilst the undelayed signal or its IFFT only goes through another channel $h_2(n;k)$ between the base station multiple transmit antennae and the receive antenna, thereby creating two different channels which can be space-time decoded to recover the transmitted signal.

17. A method according to Claim 15, wherein the beamforming weights being chosen such that the average transmit SINR function at the base station is maximized for each clustered ray.

18. A method according to Claim 15, wherein the beamforming weights being chosen such that the average receive SINR function at the mobile terminal is maximized.

19. A method according to Claim 15, wherein the beamforming weights for each clustered ray are chosen as the principal eigenvector of the downlink channel covariance matrix (DCCM) corresponding to that clustered ray.

20. A method according to Claim 15, comprising the further steps of:

estimating a power-delay-DOA profile for channel $h(n;k)$; and, based on the profile: determining the cyclic prefix, $\Delta\psi$, to be added by the transmit processors; determining the delay ψ; diversity order and modulation scheme; and determining the transmit beamforming weights.

21. A method according to Claim 20, comprising the further step of estimating the downlink channel covariance matrix (DCCM) from the uplink channel covariance matrix (UCCM) to construct transmit beamforming weights.

22. A method according to Claim 21, comprising the further step of determining the diversity order and modulation scheme based on the profile.

23. A method according to Claim 8, wherein the transmit and receive processors are selected from the group consisting of: OFDM, MC-CDMA MC-DS-CDMA and a single carrier system with cyclic prefix.

24. A base station with multiple transmit antennae for communicating with a mobile terminal having at least a single receive antenna over physical channel $h(k)$, the base station comprising:

a space-time encoder having an input of a signal to be transmitted and at least two outputs each producing a separate signal;
at least two transmit processors each receiving one of the outputs from a respective space-time encoder;
at least two transmit beamformers each receiving an output from a respective transmit processor and applying a transmit beamforming weight thereto;
a signal combiner receiving signals from the beamformers and operable to perform a summing function of the signals from the beamformers and produce a signal for transmission by the multiple transmit antennae.

25. A base station according to Claim 24, wherein the physical channel $h(n;k)$ consists of two time-delayed rays, $h_1(n;k)$ and $h_2(n;k)$, with delay $\Delta\tau$, further comprising a delay of $\Delta\tau$ interposed between one of the multiple access transmit processor outputs and a beamformer to delay the signal output from the transmit processor by $\Delta\tau$ before the respective selected transmit beamforming weight is applied thereto, wherein the transmit processors do not add cyclic prefixes.

26. A base station according to Claim 24, wherein the physical channel $h(n;k)$ consists of two time-delayed clustered rays, $h_1(n;k)$ and $h_2(n;k)$, with delay ψ and maximum excess delay for the clusters $\Delta\psi$, further comprising a delay of ψ interposed between one of the multiple access transmit processor outputs and a beamformer to delay the signal output from the transmit processor by ψ before the respective selected transmit beamforming weight is applied thereto, the transmit processors having a cyclic prefix length of $\Delta\psi$.

27. A base station according to Claim 24, further comprising a first processor to determine a power-delay-DOA profile estimate for channel $h(n;k)$; and, based on the profile, determine: the length, $\Delta\psi$, of the cyclic prefix to be added by the transmit processors; the delay ψ; diversity order and modulation scheme; and the transmit beamforming weights.

28. A base station according to Claim 27, further comprising a second processor to estimate a downlink channel covariance matrix (DCCM) from the uplink channel covariance matrix (UCCM) to construct transmit beamforming

weights.

29. A base station according to Claim 15, wherein the transmit and receive processors are selected from the group consisting of: OFDM, MC-CDMA MC-DS-CDMA and single carrier system with cyclic prefix.

30. A communications system comprising the base station of Claim 24 and a mobile terminal having at least a single receive antenna, a receive processor to produce an output signal and a space-time decoder to decode the output signal.

31. A method of achieving combined beamforming and transmit diversity for frequency selective fading channels in a communication system having a base station with multiple transmit antennae and a mobile terminal with at least a single receive antenna, the method comprising the steps of:

providing a signal to be transmitted *s(n)*;
space-time encoding a signal to be transmitted *s(n)* to produce at least two separate signals $s_1(n), s_2(n)$, each on a respective output;
delaying one of the space-time encoded output signals by $\Delta\tau$;
applying respective selected transmit beamforming weights to the delayed and undelayed signals;
feeding the respective weighted signals to a signal combiner to perform a summing function of the signals and produce a signal for transmission;
feeding the summed signal to each of the multiple transmit antennae for transmission;
transmitting the summed signals over the physical channel h(k);
receiving the major components of the transmitted signals at at least a single receive antenna at substantially the same time; and
space-time decoding the received signal.

32. A method according to Claim 31, wherein the physical channel h(k) consists of two time-delayed rays $h_1(k)$, $h_2(k)$ with delay $\Delta\tau$, the beamforming weights are chosen such that the delayed signal only goes through one ray $h_1(k)$ between the base station multiple transmit antennae and the receive antenna, whilst the undelayed signal only goes through another ray $h_2(k)$ between the base station multiple transmit antennae and the receive antenna.

33. A method according to Claim 31, wherein the physical channel h(k) consists of two time-delayed rays $h_1(k)$, $h_2(k)$ with delay $\Delta\tau$, the beamforming weights are chosen such that the average transmit SINR function at the base station is maximized for each ray.

34. A method according to Claim 31, wherein the physical channel h(k) consists of two time-delayed rays $h_1(k)$, $h_2(k)$ with delay $\Delta\tau$, the beamforming weights are chosen such that the average receive SINR function at the mobile terminal is maximized.

35. A method according to Claim 31, wherein the physical channel h(k) consists of two time-delayed rays $h_1(k)$, $h_2(k)$ with delay $\Delta\tau$, the beamforming weights for each ray are chosen as the principal eigenvector of the downlink channel covariance matrix (DCCM) corresponding to that ray.

36. A method according to Claim 31, wherein the physical channel h(k) consists of two time-delayed rays $h_1(k)$, $h_2(k)$ with delay $\Delta\tau$, the delay $\Delta\tau$ is derived from downlink channel information.

37. A method according to Claim 31, wherein the physical channel h(k) consists of two time-delayed rays $h_1(k)$, $h_2(k)$ with delay $\Delta\tau$, the delay $\Delta\tau$ is derived from uplink channel information.

38. A method according to Claim 31, wherein the physical channel h(k) consists of multiple rays with two major rays $h_1(k)$, $h_2(k)$ delayed by $\Delta\tau$, the beamforming weights are chosen such that the delayed signal only goes through one ray $h_1(k)$ between the base station multiple transmit antennae and the receive antenna, whilst the undelayed signal only goes through another ray $h_2(k)$ between the base station multiple transmit antennae and the receive antenna.

39. A method according to Claim 31, wherein the physical channel h(k) consists of multiple rays with two major rays $h_1(k)$, $h_2(k)$ delayed by $\Delta\tau$, the beamforming weights are chosen such that the average transmit SINR function at the base station is maximized for each ray.

40. A method according to Claim 31, wherein the physical channel h(k) consists of multiple rays with two major rays $h_1(k)$, $h_2(k)$ delayed by $\Delta\tau$, the beamforming weights are chosen such that the average receive SINR function at the mobile terminal is maximized.

41. A method according to Claim 31, wherein the physical channel h(k) consists of multiple rays with two major rays $h_1(k)$, $h_2(k)$ delayed by $\Delta\tau$, the beamforming weights for each ray are chosen as the principal eigenvector of the downlink channel covariance matrix (DCCM) corresponding to that ray.

42. A method according to Claim 31, wherein the physical channel h(k) consists of multiple rays with two major rays $h_1(k)$, $h_2(k)$ delayed by $\Delta\tau$, the delay $\Delta\tau$ is derived from downlink channel information.

43. A method according to Claim 31, wherein the physical channel h(k) consists of multiple rays with two major rays $h_1(k)$, $h_2(k)$ delayed by $\Delta\tau$, the delay $\Delta\tau$ is derived from uplink channel information.

44. A base station with multiple transmit antennae for communicating with a mobile terminal having at least a single receive antenna over physical channel $h(k)$ having two time-delayed rays, $h_1(k)$ and $h_2(k)$, the base station comprising:

a space-time encoder having an input of a signal to be transmitted and at least two outputs each producing a separate signal;
at least two transmit beamformers each receiving an output from the space-time encoder and applying a transmit beamforming weight thereto;
a signal combiner receiving signals from the beamformers and operable to perform a summing function of the signals from the beamformers and produce a signal for transmission by each of the multiple transmit antennae, wherein a delay of $\Delta\tau$ is interposed between the space-time encoder and one of the beamformers such that the major components of the transmitted signals are received at at least a single receive antenna at substantially the same time.

45. A communications system comprising the base station of Claim 24 and a mobile terminal having at least a single receive antenna and a space-time decoder to decode the received signal.

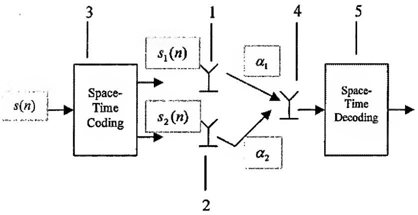


Figure1: Prior Art

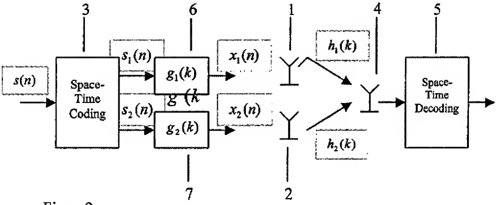


Figure2

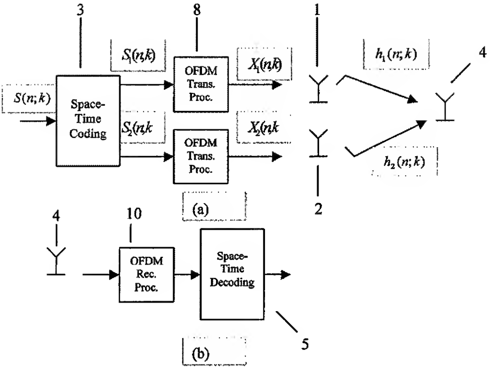


Figure3: Prior Art

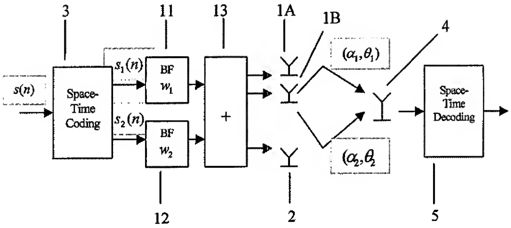


Figure4: Prior Art

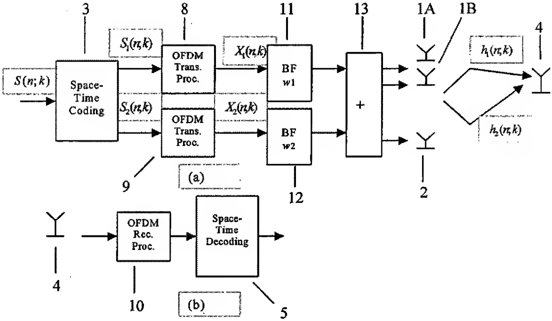

3
8
11
13
1A
1B
4
$S(n;k)$
$S_1(n,k)$
$S_2(n,k)$
Space-Time Coding
OFDM Trans. Proc.
OFDM Trans. Proc.
$X_1(n,k)$
$X_2(n,k)$
BF w1
BF w2
+
$h_1(n,k)$
$h_2(n,k)$
9
(a)
12
2
OFDM Rec. Proc.
Space-Time Decoding
4
10
(b)
5

Figure5

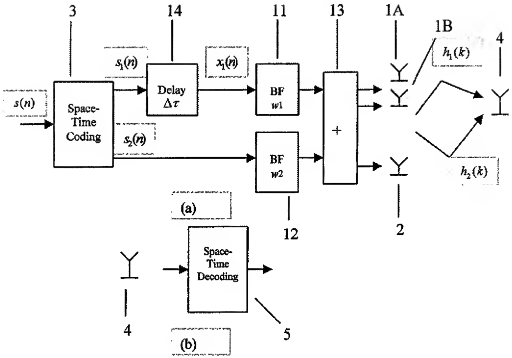

3
14
11
13
1A
1B
4
$s_1(n)$
$x_1(n)$
$h_1(k)$
$s(n)$
Space-Time Coding
Delay $\Delta\tau$
BF $w1$
+
$s_2(n)$
BF $w2$
$h_2(k)$
(a)
12
2
Space-Time Decoding
4
5
(b)

Figure6

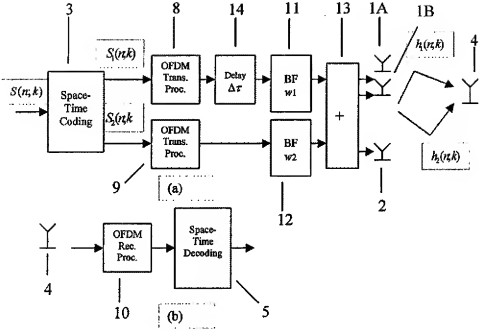

3
8
14
11
13
1A
1B
$S_1(n,k)$
$h_1(n,k)$
4
$S(n;k)$
Space-Time Coding
OFDM Trans. Proc.
Delay $\Delta\tau$
BF $w1$
+
$S_2(n,k$
OFDM Trans. Proc.
BF $w2$
$h_2(n,k)$
9
(a)
2
12
OFDM Rec. Proc.
Space-Time Decoding
4
10
(b)
5

Figure7

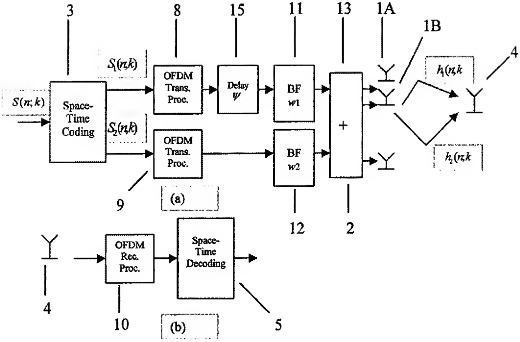
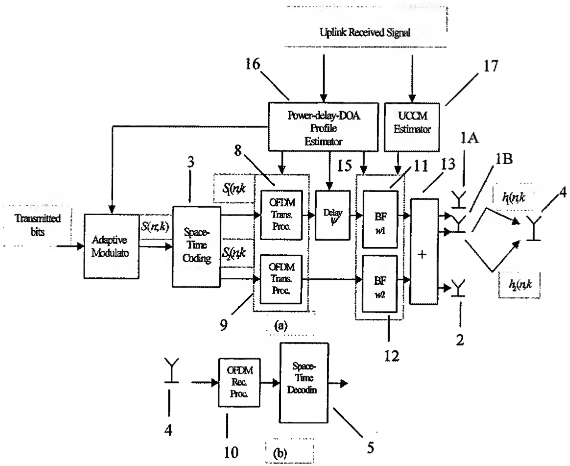

3
8
15
11
13
1A
1B
4
$S_1(n,k)$
$S(n;k)$
Space-Time Coding
$S_2(n,k)$
OFDM Trans. Proc.
Delay ψ
BF w1
+
$h_1(n,k$
OFDM Trans. Proc.
BF w2
$h_2(n,k$
9
(a)
12
2
OFDM Rec. Proc.
Space-Time Decoding
4
10
(b)
5

Figure8



Uplink Received Signal
16
17
Power-delay-DOA Profile Estimator
UCCM Estimator
1A
1B
8
3
15
11
13
S(n,k
Transmitted bits
Adaptive Modulato
S(n,k)
Space-Time Coding
S(n,k
OFDM Trans. Proc.
Delay
BF w1
BF w2
+
h(n,k
4
h(n,k
2
9
(a)
12
OFDM Rec. Proc.
Space-Time Decodin
4
10
(b)
5

Figure9

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 02 25 4685

DOCUMENTS CONSIDERED TO BE RELEVANT

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X	LIU Z ET AL: "Transmit-antennae space-time block coding for generalized OFDM in the presence on unknown multipath" IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, IEEE INC. NEW YORK, US, vol. 19, no. 7, July 2001 (2001-07), pages 1352-1364, XP001112325 ISSN: 0733-8716 * abstract * * section II * * figure 1 *	1-7	TECHNICAL FIELDS SEARCHED (Int.Cl.7) H04L
A	YANG H ET AL: "An adaptive channel precoded space-time transmitter for 3GPP TDD system" GLOBECOM '01. 2001 IEEE GLOBAL TELECOMMUNICATIONS CONFERENCE. SAN ANTONIO, TX, IEEE GLOBAL TELECOMMUNICATIONS CONFERENCE, NEW YORK, NY: IEEE, US, vol. 1 OF 6, 25 - 29 November 2001, pages 529-532, XP001090311 ISBN: 0-7803-7206-9 * section II-B * * figure 3 *	1-7	
	-/--		

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	10 April 2003	Ghigliotti, L

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
O : non-written disclosure
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L : document cited for other reasons

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EUROPEAN SEARCH REPORT

Application Number
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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A,D	ALAMOUTI S M: "A simple transmit diversity technique for wireless communications" IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, IEEE INC. NEW YORK, US, vol. 16, no. 8, October 1998 (1998-10), pages 1451-1458, XP002100058 ISSN: 0733-8716 * the whole document *	1,6	
A,D	TAROKH V ET AL: "Space-time codes for high data rate wireless communication: performance criterion and code construction" IEEE TRANSACTIONS ON INFORMATION THEORY, IEEE INC. NEW YORK, US, vol. 44, no. 2, 1 March 1998 (1998-03-01), pages 744-765, XP002089112 ISSN: 0018-9448 * the whole document *	1-7	
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X	WO 01 78254 A (NOKIA NETWORKS OY ;KATZ MARCOS (FI); KESKITALO ILKKA (FI); YLITALO) 18 October 2001 (2001-10-18) * page 14, line 10 - page 15, line 14 * * figure 3 *	8-45	

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	10 April 2003	Ghigliotti, L

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European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 02 25 4685

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X,D	NEGI R ET AL: "Adaptive antennas for space-time coding over block-time invariant multipath fading channels" VEHICULAR TECHNOLOGY CONFERENCE, 1999 IEEE 49TH HOUSTON, TX, USA 16-20 MAY 1999, PISCATAWAY, NJ, USA,IEEE, US, 16 May 1999 (1999-05-16), pages 70-74, XP010341916 ISBN: 0-7803-5565-2 * section 3 *	8-22, 24-28	
A,D	EP 1 087 545 A (UNIV SINGAPORE) 28 March 2001 (2001-03-28) * the whole document *	8-45	
			TECHNICAL FIELDS SEARCHED (Int.Cl.7)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	10 April 2003	Ghigliotti, L

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L : document cited for other reasons

& : member of the same patent family, corresponding document

European Patent Office

Application Number
EP 02 25 4685

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing more than ten claims.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☒ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☐ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

European Patent Office

LACK OF UNITY OF INVENTION SHEET B

Application Number
EP 02 25 4685

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. Claims: 1-7

   Method and system for achieving diversity gain in frequency selective fading channel, by means of space-time encoding and zero-forcing pre-equalisation.

2. Claims: 8-45

   Method and system for achieving simultaneous beamforming and transmit diversity gain by means of a a space-time encoder and a transmit beamformer.

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 02 25 4685

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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10-04-2003

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
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			EP	1287627 A2	05-03-2003
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EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 387 545 A2

(12) EUROPEAN PATENT APPLICATION

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(51) Int Cl.7: H04L 27/26

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(22) Date of filing: 16.07.2003

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AL LT LV MK

(30) Priority: 29.07.2002 KR 2002044630

(71) Applicant: SAMSUNG ELECTRONICS CO., LTD.
Suwon-City, Kyungki-do (KR)

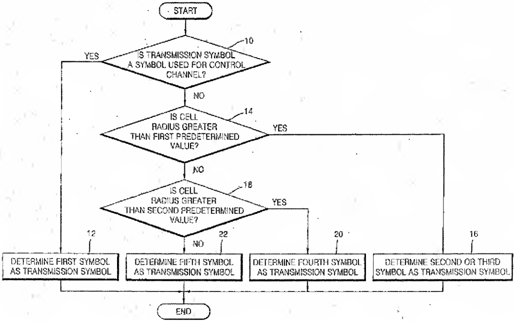
(72) Inventors:
- Hwang, Chan-soo
Kiheung-eub, Yongin-city Kyungki-do (KR)
- Kim, Yung-soo 109-2401 Kachi Maeul
Seongnam-city Kyungki-do (KR)

(74) Representative: Ertl, Nicholas Justin
Elkington and Fife,
Prospect House,
8 Pembroke Road
Sevenoaks, Kent TN13 1XR (GB)

(54) Multicarrier transmission with adaptation to channel characteristics

(57) An orthogonal frequency division multiplexing (OFDM) communication method and apparatus adapted to channel characteristics are provided. The OFDM communication method includes changing at least one of a length of a transmission symbol, a format of a frame, and a format of the transmission symbol depending on a type of the transmission symbol and a radius of a cell, in which communication is performed. The OFDM communication apparatus includes a symbol inspector, for inspecting a type of a transmission symbol and outputting the result of the inspection as a first control signal, and a symbol and format converter, for changing at least one of a length of a transmission symbol, a format of a frame, and a format of the transmission symbol in response to the first control signal and a radius of a cell, in which communication is performed.

FIG. 1



EP 1 387 545 A2

Description

[0001] The present invention relates to orthogonal frequency division multiplexing (OFDM) communication, and more particularly, to an OFDM communication method and apparatus adapted to channel characteristics.

[0002] With a variety of environments in which a communication method is used, the communication method is required to be effective even if Doppler frequency or delay spread changes. However, since an optimum physical layer varies with channel change speed and delay spread, it is difficult to efficiently support a communication method using a single physical layer. Accordingly, a hierarchical cell including a variety of cells is used in a single communication method.

[0003] When using such a hierarchical cell, channels for users corresponding to different layers have different characteristics. For example, when a cell has a large radius, delay spread is long, and a channel change speed is fast. Accordingly, if the same modulation method is applied to different layers, a communication method cannot be adapted to the channel characteristics. In order to overcome this problem, a conventional communication method uses OFDM when the channel change speed is slow and uses code division multiple access (CDMA) when the channel change speed is fast. As described above, when using the conventional communication method, two modems of different types need to be provided for a terminal. Accordingly, the conventional communication method increases the complexity of transmitter and receiver of a terminal. In addition, since signals having different spectrum characteristics are used, the conventional communication method is difficult to develop, and radio resource management such as handover and association is difficult.

[0004] According to an aspect of the present invention, there is provided an OFDM communication method adapted to channel characteristics, including changing at least one of a length of a transmission symbol, a format of a frame, and a format of the transmission symbol depending on a type of the transmission symbol and a radius of a cell, in which communication is performed.

[0005] The invention thus provides an orthogonal frequency division multiplexing (OFDM) communication method through which at least one of the length of a transmission symbol, the format of a transmission symbol, and the format of a frame is changed to adapt to channel characteristics such as channel change speed and channel spread.

[0006] According to another aspect of the present invention, there is provided an OFDM communication apparatus adapted to channel characteristics, including a symbol inspector, which inspects a type of a transmission symbol and outputs the result of the inspection as a first control signal; and a symbol and format converter, which changes at least one of a length of a transmission symbol, a format of a frame, and a format of the transmission symbol in response to the first control signal and a radius of a cell, in which communication is performed.

[0007] The invention thus also provides an OFDM communication apparatus for performing the OFDM communication method of the invention, which is adapted to the channel characteristics.

[0008] The above and other features and advantages of the present invention will become more apparent by describing in detail preferred embodiments thereof with reference to the attached drawings in which:

FIG. 1 is a flowchart of an orthogonal frequency division multiplexing (OFDM) communication method adapted to channel characteristics according to a first embodiment of the present invention;
FIG. 2 is a diagram showing an example of a single frame including symbols having various lengths;
FIG. 3 is a flowchart of an OFDM communication method adapted to channel characteristics according to a second embodiment of the present invention;
FIG. 4 is a diagram showing an example of a macro format;
FIG. 5 is a diagram showing an example of a micro format;
FIG. 6 is a diagram showing an example of a pico format;
FIG. 7 is a flowchart of an embodiment of step 16 shown in FIG. 1 according to the present invention;
FIG. 8 is a diagram showing a hierarchical cell structure;
FIG. 9 is a diagram showing an example of a usual multiplex carrier wave transmission symbol;
FIG. 10 is a diagram showing another example of a usual multiplex carrier wave transmission symbol;
FIG. 11 is a diagram showing still another example of a usual multiplex carrier wave transmission symbol;
FIG. 12 is a block diagram of an OFDM communication apparatus for performing an OFDM communication method of the present invention, according to an embodiment of the present invention;
FIG. 13 is a block diagram of an embodiment of a symbol and format converter shown in FIG. 12;
FIG. 14 is a block diagram of another embodiment of the symbol and format converter shown in FIG. 12;
FIG. 15 is a block diagram of a first converter shown in FIG. 13;
FIG. 16 is a graph showing changes in a bit error rate with respect to changes in Doppler frequency; and
FIG. 17 is a graph showing changes in a bit error rate with respect to changes in the number of carrier waves.

[0009] Hereinafter, preferred embodiments of an orthogonal frequency division multiplexing (OFDM) communication

method to adapt to channel characteristics according to the present invention will be described in detail with reference to the attached drawings. In an OFDM communication method to adapt to channel characteristics according to the present invention, at least one of the length of a transmission symbol, the format of a frame, and the format of a transmission symbol is changed depending on a type of transmission symbol and the radius of a cell, in which communication is performed.

[0010] Channel variation is usually measured in terms of Doppler frequency multiplied by the length of an OFDM symbol, denoted as fdTs (fd: Doppler frequency in Hz, Ts; symbol duration in seconds). When fdTs is less than 0.01, the effect of channel variation on the detection performance is negligible. However, when fdTs becomes greater than 0.01, the effect becomes noticeable. Generally speaking, a fast channel change speed is when fdTs is greater than 0.01, though this is not a hard and fast rule.

[0011] Likewise, the channel length is measured by the delay spread of a channel, which is the time delay incurred from when the first signal components arrive at the receiver to when the last signal components arrive at the receiver. For example, if the last signal arrives at the receiver 0.01 seconds after the first signal arrived at the receiver, the length of the channel is 0.01 seconds. A long, medium or short channel is a relative measure utilized in the industry to describe this relative channel length. For example, if the default symbol length is 0.1 msec, a 0.1-msec channel is considered to be a long channel, a 0.01-msec channel is considered to be a medium channel, and a 0.001-msec is considered to be a short channel. In other words, when the length of a channel, divided by the length of the default OFDM symbol, is more than 10%, it is considered to be a long channel.

[0012] FIG. 1 is a flowchart of an OFDM communication method to adapt to channel characteristics according to a first embodiment of the present invention. The OFDM communication method according to the first embodiment includes determining the length of a transmission symbol depending on a type of transmission symbol and a cell radius (steps 10 through 22).

[0013] FIG. 2 is a diagram showing an example of a single frame 40, in which symbols having various lengths are mixed. The single frame 40 includes first symbols 42 and 44, second symbols 50 and 52, third symbols 54, 56, 58, and 60, a fourth symbol 48, and a fifth symbol 46.

[0014] In the OFDM communication method according to the first embodiment of the present invention shown in FIG. 1, the length of a transmission symbol is changed depending on a type of transmission symbol and the radius of a cell, in which communication is performed.

[0015] More specifically, it is determined whether a transmission symbol is a symbol that is used for a control channel in step 10. If it is determined that the transmission symbol is the symbol that is used for the control channel, the first symbol 42 or 44 shown in FIG. 2 is determined as the transmission symbol in step 12. The first symbol 42 or 44 contains control information and has a length A. In other words, if it is determined that the transmission symbol is the symbol that is used for the control channel, the length of the transmission symbol is set to A. As described above, when a large amount of data is not necessary or when it is necessary to finely divide time, as in random access or control, the relatively short length A is determined as the length of a transmission symbol.

[0016] If it is determined that the transmission symbol is not the symbol that is used for the control channel, it is determined whether a cell radius is greater than a first predetermined value in step 14. If it is determined that the cell radius is greater than the first predetermined value, the second symbol 50 or 52 or the third symbol 54, 56, 58, or 60 shown in FIG. 2 is determined as the transmission symbol in step 16. The second symbol 50 or 52 has a length B and is suitable to channel characteristics, in which a channel change speed is slow and the length of a channel is long. The third symbol 54, 56, 58, or 60 has a length C and is suitable to channel characteristics, in which a channel change speed is fast and the length of a channel is long or short. In other words, if it is determined that the cell radius is greater than the first predetermined value, the length of the transmission symbol is set to B or C.

[0017] However, if it is determined that the cell radius is not greater than the first predetermined value, it is determined whether the cell radius is greater than a second predetermined value in step 18. Here, the second predetermined value is less than the first predetermined value. If it is determined that the cell radius is greater than the second predetermined value, the fourth symbol 48 shown in FIG. 2 is determined as the transmission symbol in step 20. The fourth symbol 48 has a length D and is suitable to channel characteristics, in which a channel change speed and the length of a channel are medium. In other words, if it is determined that the cell radius is not greater than the first predetermined value but greater than the second predetermined value, the length of the transmission symbol is set to D.

[0018] However, if it is determined that the cell radius is not greater than the second predetermined value, the fifth symbol 46 shown in FIG. 2 is determined as the transmission symbol in step 22. The fifth symbol 46 has a length E and is suitable to channel characteristics, in which a channel change speed is slow and the length of a channel is short. In other words, if it is determined that the cell radius is not greater than the second predetermined value, the length of the transmission symbol is set to E.

[0019] According to the present invention, the length D of the fourth symbol 48 is shorter than the length B of the second symbol 50, and each of the lengths A, C, and E of the respective first, third, and fifth symbols 42, 54, and 46 is shorter than the length D of the fourth symbol 48. In addition, according to the present invention, each of the lengths

B, C, D, and E of the respective second, third, fourth, and fifth symbols 50, 54, 48, and 46 may be an integer multiple of the length A of the first symbol 42, and each of the lengths B, C, and D of the respective second, third, and fourth symbols 50, 54, and 48 may be an integer multiple of the length E of the fifth symbol 46.

[0020] In order to change the length of a transmission symbol, as shown in FIG. 1, the present invention changes the number of carrier waves while fixing an entire signal bandwidth. The entire signal bandwidth indicates the result of dividing an interval between carrier waves by the length of a transmission symbol. For example, when increasing the number of carrier waves while fixing an entire signal bandwidth, a distance between carrier waves is long and the length of a transmission symbol increases. Conversely, when decreasing the number of carrier waves while fixing an entire signal bandwidth, a distance between carrier waves is short and the length of a transmission symbol decreases. As described above, the length of a transmission symbol can be changed by adjusting the number of carrier waves, in step 12, 16, 20 or 22.

[0021] FIG. 3 is a flowchart of an OFDM communication method to adapt to channel characteristics according to a second embodiment of the present invention. The OFDM communication method includes converting the format of a frame depending on a cell radius in steps 70 through 78.

[0022] FIG. 4 is a diagram showing an example of a macro format. A single frame 90 is composed of a single first symbol and a plurality of second symbols, and a plurality of third symbols.

[0023] FIG. 5 is a diagram showing an example of a micro format. A single frame 92 is composed of a single first symbol and a plurality of fourth symbols.

[0024] FIG. 6 is a diagram showing an example of a pico format. A single frame 94 is composed of a single first symbol and a plurality of fifth symbols.

[0025] In the OFDM communication method according to the second embodiment of the present invention shown in FIG. 3, the format of a frame is converted depending on the radius of a cell, in which communication is performed.

[0026] For this operation, it is determined weather a cell radius is greater than a first predetermined value in step 70. If it is determined that the cell radius is greater than the first predetermined value, the format of a frame is converted into a macro format, as shown in FIG. 4, in step 72. Referring to FIG. 4, the macro format is composed of a single first symbol, a plurality of second symbols, and a plurality of third symbols. In other words, when a channel change speed is fast or slow and the length of a channel is long due to a large cell radius, the format of the frame is converted into the macro format shown in FIG. 4.

[0027] However, if it is determined that the cell radius is not greater than the first predetermined value, it is determined weather the cell radius is greater than a second predetermined value in step 74. The second predetermined value is smaller than the first predetermined value. If it is determined that the cell radius is greater than the second predetermined value, the format of a frame is converted into a micro format, as shown in FIG. 5, in step 76. Referring to FIG. 5, the micro format is composed of a single first symbol and a plurality of fourth symbols. In other words, when a channel change speed and the length of a channel are medium, the format of the frame is converted into the micro format.

[0028] However, if it is determined that the cell radius is not greater than the second predetermined value, the format of a frame is converted into a pico format, as shown in FIG. 6, in step 78. Referring to FIG. 6, the pico format is composed of a single first symbol and a plurality of fifth symbols. In other words, when a channel change speed is slow and the length of a channel is short due to a small cell radius, the format of the frame is converted into the pico format.

[0029] FIG. 7 is a flowchart of an embodiment of step 16 shown in FIG. 1 according to the present invention. The embodiment of step 16 includes determining a second or third symbol as a transmission symbol depending on a channel change speed in steps 110 through 114.

[0030] Referring to FIG. 7, if it is determined that the cell radius is greater than the first predetermined value (step 14 of FIG. 1), it is determined whether a channel change speed is greater than a predetermined speed in step 110.

[0031] If it is determined that the channel change speed is not greater than the predetermined speed, the second symbol 50 shown in FIG. 2 is determined as the transmission symbol in step 112. In other words, the length of the transmission symbol is set to B. However, if it is determined that the channel change speed is greater than the predetermined speed, the third symbol 54 is determined as the transmission symbol in step 114. In other words, the length of the transmission symbol is set to C.

[0032] According to a third embodiment of the present invention, the length of a transmission symbol and the format of a frame are changed depending on a type of transmission symbol and a cell radius. For this operation, referring to FIG. 1, if it is determined that the cell radius is greater than the first predetermined value, the second or third symbol is determined as the transmission symbol, and simultaneously the format of the frame is converted into the macro format shown in FIG. 4, in step 16. However, if it is determined that the cell radius is not greater than the first predetermined value but is greater than the second predetermined value, the fourth symbol is determined as the transmission symbol, and simultaneously the format of the frame is converted into the micro format shown in FIG. 5, in step 20. In addition, if it is determined that the cell radius is not greater than the second predetermined value, the fifth symbol is determined as the transmission symbol, and simultaneously the format of the frame is converted into the pico format shown in FIG. 6, in step 22.

[0033] FIG. 8 is a diagram showing a hierarchical cell structure, which is composed of macro cells 130, micro cells 132, and pico cells 134.

[0034] Referring to FIG. 8, the macro cells 130 represented by dotted lines correspond to cells having a radius that is greater than the first predetermined value. The micro cells 132 represented by bold sold lines correspond to cells having a radius that is not greater than the first predetermined value but greater than the second predetermined value. The pico cells 134 represented by thin solid lines correspond to cells having a radius that is not greater than the second predetermined value. The hierarchical cell structure shown in FIG. 8 is used in order to increase frequency efficiency when frequency resources are limited. As shown in FIG. 8, a plurality of micro cells 132 exist within each macro cell 130, and a plurality of pico cells 134 exist within each micro cell 132. Usually, the hierarchical cell structure is designed such that users with a fast channel change speed are gathered at the macro cells 130 and users with a slow channel change speed are gathered in the micro cells 132 or the pico cells 134. This is disclosed in pages 301-304 of a book entitled "Radio Resource Management for Wireless Networks", written by Jens Zander and Seong-Lyun Kim, and published by Artech Houser in 2001.

[0035] FIG.s 9 to 11 show examples of the multiplex carrier wave transmission symbol. FIG. 9 is an example of the second symbol and FIG.s 10 and 11 are different examples of the third symbol. In the following description, the different parts of the symbols of different examples are each given different names to avoid confusion. Therefore, the existence of a "third cyclic prefix" (for example) in a symbol should not be understood as requiring a "first" or "second" cyclic prefix in that symbol.

[0036] FIG. 9 is a diagram showing an example of a multiplex carrier wave transmission symbol. In this example, the transmission symbol is composed of a first cyclic prefix (CP) 150, a first transmission signal 158, and a first cyclic suffix (CS) 154.

[0037] According to the fourth embodiment of the present invention, the format of a symbol as well as the length of the symbol can be changed depending on a cell radius and a channel change speed.

[0038] For example, if it is determined that the channel change speed is not greater than the predetermined speed, the second symbol is determined as the transmission symbol and the format of the second symbol is converted into a format shown in FIG. 9 in step 112 of FIG. 7. In FIG. 9, the first CP 150 of the transmission symbol is the result of copying an end portion 152 of the first transmission signal 158 to the front of the first transmission signal 158 and is used to eliminate the interference of a previous symbol. The first CS 154 of the transmission symbol is the result of copying a beginning portion 156 of the first transmission signal 158 to the back of the first transmission signal 158 and is used to mitigate the alignment condition of transmission time when a carrier wave is divided and used by multiple users usually in an upward channel. Here, the first transmission signal 158 contains transmission data. As described above, since the end portion 152 of the transmission data 158 is copied to the first CP 150 and the beginning portion 156 of the transmission data 158 is copied to the first CS 154, the transmission symbol shown in FIG. 9 has a cyclic structure.

[0039] FIG. 10 is a diagram showing another example of a multiplex carrier wave transmission symbol. In this example, the transmission symbol is composed of a second CP 170, second and third transmission signals 172 and 174, and a second CS 176.

[0040] FIG. 11 is a diagram showing still another example of a multiplex carrier wave transmission symbol. In this example, the transmission symbol is composed of a third CP 190, fourth and fifth transmission signals 192 and 194, and a third CS 196.

[0041] However, if it is determined that the channel change speed is greater than the predetermined speed, the third symbol is determined as the transmission symbol and the format of the third symbol is converted into a format shown in FIG. 10 or 11 in step 114 of FIG. 7.

[0042] According to the present invention, the second CP 170 of the third symbol shown in FIG. 10 includes the end portion of transmission data stored in each of the second and third transmission signals 172 and 174 and the beginning portion of the transmission data. In other words, the second CP 170 is composed of two first CPs 150 and one first CS 154 shown in FIG. 9. In addition, each of the second and third transmission signals 172 and 174 shown in FIG. 10 contains the same transmission data as that contained in the first transmission signal 158 shown in FIG. 9. Unlike the transmission symbol shown in FIG. 9, the transmission symbol shown in FIG. 10 includes repeated transmission data following the second CP 170. Here, the second CS 176 includes the beginning portion of the transmission data. In other words, the second CS 176 is composed of one first CS 154 shown in FIG. 9.

[0043] According to the present invention, the third CP 190 of the third symbol shown in FIG. 11 includes the end portions of transmission data stored in each of the fourth and fifth transmission signals 192 and 194. In other words, the third CP 190 is composed of only two first CPs 150. In addition, each of the fourth and fifth transmission signals 192 and 194 shown in FIG. 11 contains the same transmission data as that contained in the first transmission signal 158 shown in FIG. 9. Unlike the transmission symbol shown in FIG. 9, the transmission symbol shown in FIG. 11 includes repeated transmission data following the third CP 190. Here, the third CS 196 includes the beginning portions of the transmission data. In other words, the third CS 196 is composed of two first CSs 154 shown in FIG. 9. The

transmission symbol shown in FIG. 11 can be used when timing does not agree well as a whole as in random access.

[0044] Consequently, in an OFDM communication method, the length of the first CP 150 is required to be longer than a channel length. However, since duplicate information is contained in the first CP 150, communication efficiency is decreased when the result of dividing the length of the first CP 150 by the transmission data contained in the first transmission signal 158 is too large. Accordingly, in order to maintain the communication efficiency, the length of the transmission data needs to be 5-10 times longer than the length of the first CP 150. In other words, in the transmission symbol, the length of the first CP 150 needs to be as short as possible. Here, if the length of the transmission symbol is long in a state in which a channel change speed is fast, a channel may change within the transmission data, and thus communication performance may be degraded. As described above, it is necessary to increase the length of the first CP 150 as a channel length increases, but there is a limitation in increasing the length of the first CP 150. In order to solve this problem, an OFDM communication method according to the present invention described above adaptively changes the length of a transmission symbol depending on a channel change speed and a cell radius, as shown in FIG. 1. As described above, influence of inter symbol interference (ISI) can be overcome while the degree of overhead due to the first CP 150 is fixed, by adaptively changing the length of a transmission symbol.

[0045] Hereinafter, the structure and operation of an OFDM communication apparatus adapted to channel characteristics according to the present invention, which performs the above-described OFDM communication method adapted to channel characteristics according to the present invention, will be described with reference to the attached drawings.

[0046] FIG. 12 is a block diagram of an OFDM communication apparatus for performing the above-described OFDM communication method according to an embodiment of the present invention. The OFDM communication apparatus includes a symbol inspector 210 and a symbol and format converter 212.

[0047] Referring to FIG. 12, in order to perform step 10 shown in FIG. 1, the symbol inspector 210 inspects the type of a transmission symbol that is input through an input terminal IN1 and outputs the result of the inspection to the symbol and format converter 212 as a first control signal C1. For example, the symbol inspector 210 inspects whether the transmission symbol input through the input terminal IN1 is a symbol used for a control channel and outputs the result of the inspection as the first control signal C1.

[0048] In order to perform steps 12 through 22 shown in FIG. 1, the symbol and format converter 212 changes at least one of the length of the transmission symbol, the format of a frame, and the format of the transmission symbol in response to a cell radius that is input through an input terminal IN2 and the first control signal C1 received from the symbol inspector 210, and outputs the result of the change through an output terminal OUT1. Here, what will be changed among the length of the transmission symbol, the format of a frame, and the format of the transmission symbol is predetermined.

[0049] The following description concerns the structures and operations of embodiments of the symbol and format converter 212 shown in FIG. 12 according to the present invention. FIG.s 13 and 14 each show an example of the converter 212. In the following description, the different parts of the converter in the two examples are each given different names to avoid confusion. Therefore, the existence of a "third comparator" (for example) in the converter should not be understood as requiring a "first" or "second" comparator in that converter.

[0050] FIG. 13 is a block diagram of an embodiment 212A of the symbol and format converter 212 shown in FIG. 12. The embodiment 212A includes a first comparator 230, a second comparator 232, and a first converter 234.

[0051] In order to perform step 14 shown in FIG. 1, the first comparator 230 of the symbol and format converter 212A shown in FIG. 13 compares the cell radius that is input through an input terminal IN3 with a first predetermined value in response to the first control signal C1 that is input from the symbol inspector 210 and outputs the result of the comparison to the second comparator 232 and the first converter 234 as a second control signal C2. In other words, when it is recognized based on the first control signal C1 received from the symbol inspector 210 that the transmission symbol is not a symbol used for a control channel, the first comparator 230 compares the cell radius with the first predetermined value. Here, the first predetermined value may be set in the first comparator 230 in advance, as shown in FIG. 13, or may be externally input, unlike the structure shown in FIG. 13.

[0052] In order to perform step 18 shown in FIG. 1, the second comparator 232 compares the cell radius with a second predetermined value in response to the second control signal C2 received from the first comparator 230 and outputs the result of the comparison to the first converter 234 as a third control signal C3. For example, when it is recognized based on the second control signal C2 received from the first comparator 230 that the cell radius is not greater than the first predetermined value, the second comparator 232 compares the cell radius with the second predetermined value and outputs the result of the comparison as the third control signal C3. Here, the second predetermined value may be set in the second comparator 232 in advance, as shown in FIG. 13, or may be externally input, unlike the structure shown in FIG. 13.

[0053] In order to perform steps 12, 16, 20, and 22 shown in FIG. 1, the first converter 234 determines one among first through fifth symbols as the transmission symbol in response to the first control signal C1 received from the symbol inspector 210, the second control signal C2 received from the first comparator 230, and the third control signal C3

received from the second comparator 232 and outputs the determined symbol through an output terminal OUT2. For example, in order to perform step 12, when it is recognized based on the first control signal C1 received from the symbol inspector 210 that the transmission symbol is a symbol used for a control channel, the first converter 234 determines the length of the transmission symbol as A. However, in order to perform step 16, when it is recognized based on the first and second control signals C1 and C2 that the transmission symbol is not a symbol used for a control channel and the cell radius is greater than the first predetermined value, the first converter 234 determines the length of the transmission symbol as B or C. In addition, in order to perform step 20, when it is recognized based on the first, second, and third control signals C1, C2 and C3 that the transmission symbol is not a symbol used for a control channel and the cell radius is not greater than the first predetermined value but is greater than the second predetermined value, the first converter 234 determines the length of the transmission symbol as D. In order to perform step 22, when it is recognized based on the first, second, and third control signals C1, C2 and C3 that the transmission symbol is not a symbol used for a control channel and the cell radius is not greater than the first predetermined value and is not greater than the second predetermined value, the first converter 234 determines the length of the transmission symbol as E.

[0054] FIG. 14 is a block diagram of another embodiment 212B of the symbol and format converter 212 shown in FIG. 12. The embodiment 212B includes a third comparator 250, a fourth comparator 252, and a second converter 254.

[0055] The symbol and format converter 212B shown in FIG. 14 performs the OFDM communication method shown in FIG. 3. In order to perform step 70 shown in FIG. 3, the third comparator 250 of the symbol and format converter 212B shown in FIG. 14 compares the cell radius that is input through an input terminal IN4 with the first predetermined value and outputs the result of the comparison to the fourth comparator 252 and the second converter 254 as a fourth control signal C4. Here, the first predetermined value may be set in the third comparator 250 in advance, as shown in FIG. 14, or may be externally input, unlike the structure shown in FIG. 14.

[0056] In order to perform step 74 shown in FIG. 3, the fourth comparator 252 compares the cell radius input through the input terminal IN4 with the second predetermined value in response to the fourth control signal C4 received from the third comparator 250 and outputs the result of the comparison to the second converter 254 as a fifth control signal C5. For example, when it is recognized based on the fourth control signal C4 received from the third comparator 250 that the cell radius is not grater than the first predetermined value, the fourth comparator 252 compares the cell radius with the second predetermined value and outputs the result of the comparison as the fifth control signal C5.

[0057] In order to perform steps 72, 76, and 78 of FIG. 3, the second converter 254 converts the format of a frame into a macro format, micro format, or pico format in response to the fourth control signal C4 received from the third comparator 250 and the fifth control signal C5 received from the fourth comparator 252 and outputs the frame having the converted format through an output terminal OUT3. For example, in order to perform step 72, when it is recognized based on the fourth control signal C4 that the cell radius is grater than the first predetermined value, the second converter 254 converts the format of a frame into the macro format shown in FIG. 4. In order to perform step 76, when it is recognized based on the fourth and fifth control signals C4 and C5 that the cell radius is not grater than the first predetermined value but is greater than the second predetermined value, the second converter 254 converts the format of a frame into the micro format shown in FIG. 5. In order to perform step 78, when it is recognized based on the fourth and fifth control signals C4 and C5 that the cell radius is less than both first and second predetermined values, the second converter 254 converts the format of a frame into the pico format shown in FIG. 6.

[0058] According to an embodiment of the present invention, the symbol and format converter 212 shown in FIG. 12 may be provided with the symbol and format converter 212A shown in FIG. 13 in order to perform steps 12 through 22 shown in FIG. 1 and the symbol and format converter 212B shown in FIG. 14 in order to perform the OFDM communication method shown in FIG. 3.

[0059] According to another embodiment of the present invention, the symbol and format converter 212 shown in FIG. 12 may be provided with only the symbol and format converter 212A shown in FIG. 13 in order to perform steps 12 through 22 shown in FIG. 1 and the OFDM communication method shown in FIG. 3. In this situation, the symbol and format converter 212A shown in FIG. 13 can perform all of the steps 12 through 22 shown in FIG. 1 and the OFDM communication method shown in FIG. 3. For example, the first and second comparators 230 and 232 perform steps 14 and 18, respectively, shown in FIG. 1 and also perform steps 70 and 74, respectively, shown in FIG. 3. The first converter 234 performs steps 12, 16, 20, 22, 72, 76, and 78. In other words, the first converter 234 converts the format of a frame into a macro, micro, or pico format in response to the second and third control signals C2 and C3 respectively received from the first and second comparators 230 and 232 and outputs the frame having the converted format through the output terminal OUT2. For example, in order to perform step 72, when it is recognized based on the second control signal C2 that the cell radius is greater than the first predetermined value, the first converter 234 converts the format of a frame into the macro format shown in FIG. 4. In order to perform step 76, when it is recognized based on the second and third control signals C2 and C3 that the cell radius is not greater than the first predetermined value but is greater than the second predetermined value, the first converter 234 converts the format of a frame into the micro format shown in FIG. 5. In order to perform step 78, when it is recognized based on the second and third control signals C2 and C3 that the cell radius is not greater than both first and second predetermined values, the first converter 234

converts the format of a frame into the pico format shown in FIG. 6.

[0060] FIG. 15 is a block diagram of the first converter 234 shown in FIG. 13. The first converter 234 includes a fifth comparator 270 and a format converter 272.

[0061] The first converter 234 shown in FIG. 13 may include the fifth comparator 270 in order to perform step 110 shown in FIG. 7. In this situation, the fifth comparator 270 compares a channel change speed with a predetermined speed in response to the second control signal C2 received from the first comparator 230 and outputs the result of the comparison as a sixth control signal C6. For example, when it is recognized based on the second control signal C2 that the cell radius is greater than the first predetermined value, the fifth comparator 270 compares the channel change speed with the predetermined speed and outputs the result of the comparison as the sixth control signal C6. Here, the format converter 272 of the first converter 234 converts the format of the determined transmission symbol in response to the sixth control signal C6 received from the fifth comparator 270 and outputs the transmission symbol having the converted format through the output terminal OUT2. For example, when it is recognized based on the sixth control signal C6 received from the fifth comparator 270 that the channel change speed is not greater than the predetermined speed, the format converter 272 converts the format of the transmission symbol into the format shown in FIG. 9 in order to perform step 112. However, when it is recognized based on the sixth control signal C6 received from the fifth comparator 270 that the channel change speed is greater than the predetermined speed, the format converter 272 converts the format of the transmission symbol into the format shown in FIG. 10 or 11 in order to perform step 114.

[0062] When an OFDM communication method and apparatus adapted to channel characteristics according to the present invention are used at a whole signal bandwidth of 20 MHz, the results of operation are obtained, as shown in Table 1.

Table 1

Division	First symbol	Second symbol	Third symbol	Fourth symbol	Fifth symbol
Number of carrier waves	512	4096	1024	2048	1024
Ts	0.02844	0.2275	0.05689	0.1138	0.05689
Tg	2.81	22.45	5.6	11.22	5.6
Lamp (Up) (μs)	1	1	1	1	1
CS	1	1	1	1	1
CP	0.81	20.45	3.6	9.22	3.6
Ts+Tg	0.0313	0.25	0.0625	0.125	0.0625
Bit rate	4 Mbps	8-50 Mbps	4-25 Mbps	8-50 Mbps	8-50 Mbps

[0063] Here, Ts denotes a period of time indicating the length of a transmission symbol, Tg denotes a guard time, the unit of the CS is in μs, and bps indicates bits per second.

[0064] As is seen from Table 1, in an OFDM communication method and apparatus according to the present invention, the length of a transmission symbol Ts is adjusted by changing the number of carrier waves so that the method and apparatus can be adapted to various communication environments. The transmission symbol is adjusted to adapt to various communication environments for the following reasons.

[0065] For example, let's assume that a Veh B channel, from Tr 101 146 v3.0, which is disclosed in a book entitled "Digital Communications", written by J. Proakis, and published by McGraw Hill in 1995, is used; the number of carrier waves is 4096; a whole signal bandwidth is 18 MHz; and a spread factor (SF) is 4.

[0066] FIG. 16 is a graph showing changes in a bit error rate (BER) with respect to changes in Doppler frequency. The vertical axis indicates a BER, and the horizontal axis indicates Eb/No where Eb is energy per bit and No is the variance of noise.

[0067] The BER at a Doppler frequency, i.e., a channel change speed, of 170 (■) is greater than the BER at a channel change speed of 17 (★). The BER at a channel change speed of 500 (▲) is greater than the BER at the channel change speed of 170 (■). Consequently, as is seen from FIG. 16, the BER increases with an increase in a channel change speed.

[0068] In the meantime, when the same assumption as described above is adopted, with the exception that the SF is 1, the Doppler frequency is 500, and a Veh A channel is used instead of the Veh B channel, changes in a BER with respect to changes in the number of carrier waves will be described below. Here, the channels (Veh A and Veh B) are disclosed in Table 1.2.2.3 in page 43 of a book entitled "Selection Procedures for the Choice of Radio Transmission Technologies" and published by Universal Mobile Telecommunication System (UMTS), which is under a standardization group of European Telecommunications Standardization Institute (ETSI), in Technical Report (TR) 101112 of the ETSI.

[0069] FIG. 17 is a graph showing changes in a BER with respect to changes in the number of carrier waves. The vertical axis indicates a BER, and the horizontal axis indicates Eb/No.

[0070] As shown in FIG. 17, the BER when the number of carrier waves is 2048 (■) is greater than the BER when the number of carrier waves is 1024 (▲), and the BER when the number of carrier waves is 4096 (⋆) is greater than the BER when the number of carrier waves is 2048 (■). Consequently, as is seen from FIG. 17, when the length of a transmission symbol is decreased by decreasing the number of carrier waves from 4096 to 1096, the influence of the Doppler frequency is reduced, thereby decreasing the BER. Accordingly, if transmission data is repeated two times, as shown in FIG. 10 or 11, influence due to a change in a channel length is decreased and interchannel interference is prevented.

[0071] As described above, in an OFDM communication method and apparatus to adapt to channel characteristics according to the present invention, at least one of the length and the format of a transmission symbol and the format of a frame is changed to adapt to channel characteristics such as a channel change speed and a channel length so that communication can be accomplished at a low BER and high efficiency under various environments and a terminal can be simply implemented. In particular, under an environment in which a channel change speed is fast and a channel length is long, communication reliability can be enhanced. Since the transmission symbol includes the first symbol regardless of a cell radius, as shown in FIGS. 4 through 6, the present invention facilitates wireless resource management such as association and handover.

[0072] While the present invention has been particularly shown and described with reference to exemplary embodiments thereof, it will be understood by those of ordinary skill in the art that various changes in form and details may be therein without departing from the scope of the invention as defined by the appended claims.

Claims

1. An orthogonal frequency division multiplexing (OFDM) communication method to adapt to channel characteristics, comprising the steps of changing at least one of a length of a transmission symbol, a format of a frame, and a format of the transmission symbol depending on a type of the transmission symbol and a radius of a cell, in which communication is performed.

2. The OFDM communication method of claim 1, wherein the changing steps comprises the following steps:

   (a) determining whether the transmission symbol is a symbol that is used for a control channel;
   (b) if it is determined that the transmission symbol is the symbol that is used for a control channel, determining a first symbol containing control information as the transmission symbol;
   (c) if it is determined that the transmission symbol is not the symbol that is used for a control channel, determining whether the cell radius is greater than a first predetermined value;
   (d) if it is determined that the cell radius is greater than the first predetermined value, determining a second symbol, which is suitable to channel characteristics where a channel change speed is slow and a channel length is long, or a third symbol, which is suitable to channel characteristics where the channel change speed is fast and the channel length is long, as the transmission symbol;
   (e) if it is determined that the cell radius is not greater than the first predetermined value, determining whether the cell radius is greater than a second predetermined value;
   (f) if it is determined that the cell radius is greater than the second predetermined value, determining a fourth symbol, which is suitable to channel characteristics where the channel change speed and the channel length are medium, as the transmission symbol; and
   (g) if it is determined that the cell radius is not greater than the second predetermined value, determining a fifth symbol, which is suitable to channel characteristics where the channel change speed is slow and the channel length is short, as the transmission symbol,

   wherein the second predetermined value is less than the first predetermined value, a length of the fourth symbol is less than a length of the second symbol, and a length of each of the first, third, and fifth symbols is less than the length of the fourth symbol.

3. The OFDM communication method of claim 2, wherein the length of each of the second, third, fourth, and fifth symbols is an integer multiple of the length of the first symbol.

4. The OFDM communication method of claim 2, wherein the length of each of the second, third, and fourth symbols is an integer multiple of the length of the fifth symbol.

5. The OFDM communication method of any one of claims 2 to 4, further comprising the step of adjusting the length of the determined transmission symbol by changing the number of carrier waves

6. The OFDM communication method of claim 2, wherein step (d) comprises determining the second or third symbol as the transmission symbol and converting the format of the frame into a macro format if it is determined that the cell radius is greater than the first predetermined value,

step (f) comprises determining the fourth symbol as the transmission symbol and converting the format of the frame into a micro format if it is determined that the cell radius is greater than the second predetermined value, and

step (g) comprises determining the fifth symbol as the transmission symbol and converting the format of the frame into a pico format if it is determined that the cell radius is not greater than the second predetermined value.

7. The OFDM communication method of claim 1, wherein changing step comprises the steps of:

(h) determining whether the radius cell is greater than a first predetermined value;
(i) if it is determined that the radius cell is greater than the first predetermined value, converting the format of the frame into a macro format;
(j) if it is determined that the radius cell is not greater than the first predetermined value, determining whether the radius cell is greater than a second predetermined value;
(k) if it is determined that the radius cell is greater than the second predetermined value, converting the format of the frame into a micro format; and
(l) if it is determined that the radius cell is not greater than the second predetermined value, converting the format of the frame into a pico format,

wherein the first predetermined value is greater than the second predetermined value.

8. The OFDM communication method of claim 7, wherein the macro format comprises: a first symbol, which contains control information;

a second symbol, which is suitable to channel characteristics where a channel change speed is slow and a channel length is long; and

a third symbol, which is suitable to channel characteristics where the channel change speed is fast and the channel length is long.

9. The OFDM communication method of claim 7 or 8, wherein the micro format comprises:

a first symbol, which contains control information; and
a fourth symbol, which is suitable to channel characteristics where a channel change speed and a channel length are medium.

10. The OFDM communication method of claim 7, 8 or 9, wherein the pico format comprises:

a first symbol, which contains control information; and
a fifth symbol, which is suitable to channel characteristics where a channel change speed is slow and a channel length is short.

11. The OFDM communication method of claim 2, wherein step (d) further comprises the steps of:

(d1) if it is determined that the cell radius is greater than the first predetermined value, determining whether the channel change speed is greater than a predetermined speed;
(d2) if it is determined that the channel change speed is not greater than the predetermined speed, determining the second symbol as the transmission symbol; and
(d3) if it is determined that the channel change speed is greater than the predetermined speed, determining the third symbol as the transmission symbol.

12. The OFDM communication method of claim 11, wherein the second symbol determined as the transmission symbol in step (d2) comprises:

a first cyclic prefix, which contains an end portion of transmission data;

a first transmission signal, which contains the transmission data; and
a first cyclic suffix, which contains a beginning portion of the transmission data.

13. The OFDM communication method of claim 11, wherein the third symbol determined as the transmission symbol in step (d3) comprises:

a first cyclic prefix, which contains a plurality of end portions of transmission data and a beginning portion of the transmission data;
a first transmission signal, which contains the transmission data;
a second transmission signal, which contains the transmission data; and
a first cyclic suffix, which contains the beginning portion of the transmission data.

14. The OFDM communication method of claim 11, wherein the third symbol comprises:

a first cyclic prefix, which contains a plurality of end portions of transmission data;
a first transmission signal, which contains the transmission data;
a second transmission signal, which contains the transmission data; and
a first cyclic suffix, which contains a plurality of beginning portions of the transmission data.

15. An orthogonal frequency division multiplexing (OFDM) communication apparatus to adapt to channel characteristics, comprising:

a symbol inspector, for inspecting a type of a transmission symbol and outputting the result of the inspection as a first control signal; and
a symbol and format converter, for changing at least one of a length of a transmission symbol, a format of a frame, and a format of the transmission symbol in response to the first control signal and a radius of a cell, in which communication is performed.

16. The OFDM communication apparatus of claim 15, wherein the symbol and format converter comprises:

a first comparator, for comparing the cell radius with a first predetermined value in response to the first control signal and outputting the result of the comparison as a second control signal;
a second comparator, for comparing the cell radius with a second predetermined value in response to the second control signal and outputting the result of the comparison as a third control signal; and
a first converter, for determining one among first, second, third, fourth, and fifth symbols as the transmission symbol in response to the first, second, and third control signals and outputting the determined symbol,

wherein the second predetermined value is less than the first predetermined value, the first symbol contains control information, the second symbol is suitable to channel characteristics where a channel change speed is slow and a channel length is long, the third symbol is suitable to channel characteristics where the channel change speed is fast and the channel length is long, the fourth symbol is suitable to channel characteristics where the channel change speed and the channel length are medium, and the fifth symbol is suitable to channel characteristics where the channel change speed is slow and the channel length is short.

17. The OFDM communication apparatus of claim 15 or 16, wherein the symbol and format converter comprises:

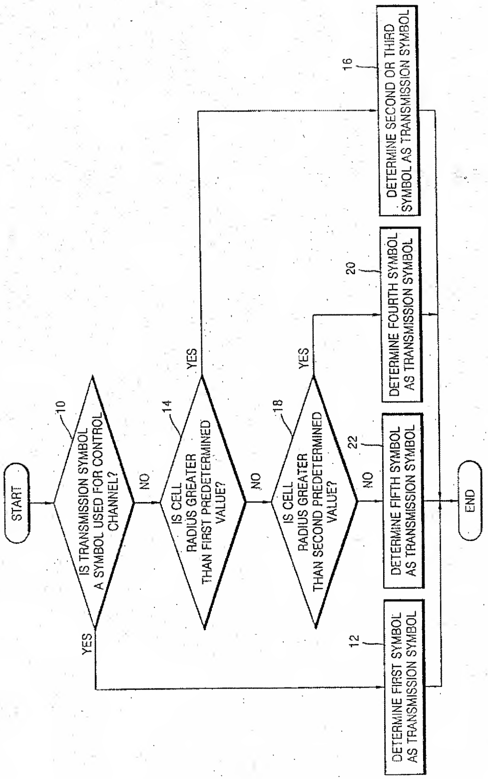
a third comparator, for comparing the cell radius with a first predetermined value and outputting the result of the comparison as a fourth control signal;
a fourth comparator, for comparing the cell radius with a second predetermined value in response to the fourth control signal and outputting the result of the comparison as a fifth control signal; and
a second converter, for converting the format of the frame into one of a macro format, a micro format, and a pico format in response to the fourth and fifth control signals,

wherein the first predetermined value is greater than the second predetermined value.

18. The OFDM communication apparatus of claim 16, wherein the first converter converts the format of the frame into one of a macro format, a micro format, and a pico format in response to the second and third control signals.

19. The OFDM communication apparatus of claim 16, wherein the first converter comprises a fifth comparator, for comparing the channel change speed with a predetermined speed in response to the second control signal and outputting the result of the comparison as a sixth control signal, and a format converter, for converting the format of the determined symbol in response to the sixth control signal.

FIG. 1


START
IS TRANSMISSION SYMBOL A SYMBOL USED FOR CONTROL CHANNEL?
10
YES
NO
DETERMINE FIRST SYMBOL AS TRANSMISSION SYMBOL
12
IS CELL RADIUS GREATER THAN FIRST PREDETERMINED VALUE?
14
YES
NO
DETERMINE SECOND OR THIRD SYMBOL AS TRANSMISSION SYMBOL
16
IS CELL RADIUS GREATER THAN SECOND PREDETERMINED VALUE?
18
YES
NO
DETERMINE FOURTH SYMBOL AS TRANSMISSION SYMBOL
20
DETERMINE FIFTH SYMBOL AS TRANSMISSION SYMBOL
22
END